EXPLORING INTERACTIVE TANGRAMS FOR TEACHING BASIC SCHOOL PHYSICS

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EXPLORING INTERACTIVE TANGRAMS FOR TEACHING BASIC SCHOOL PHYSICS

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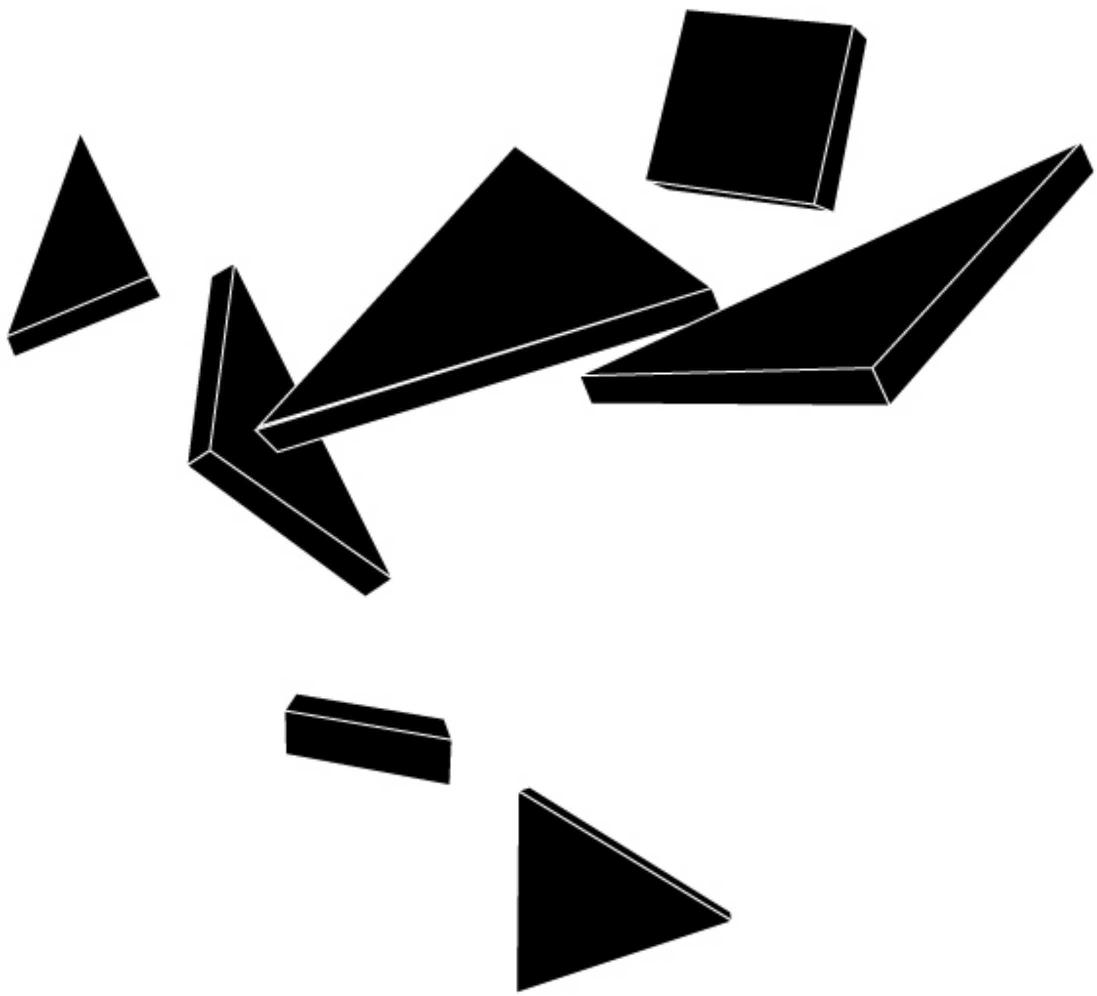

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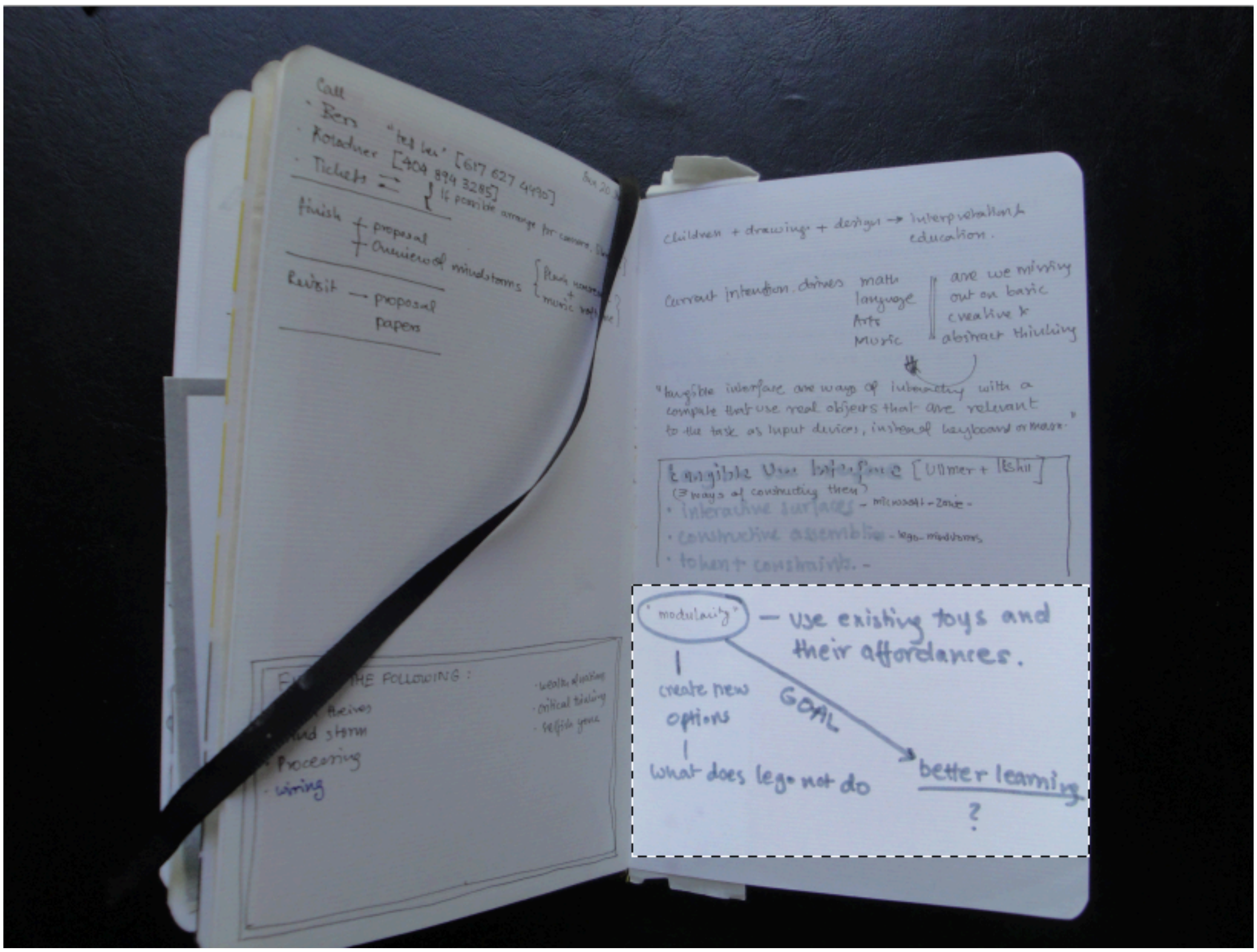


Figure 1 Identifying scope of work for thesis. the picture includes a note on tangible User Interfaces, problem space and design intent

SUMMARY

This Thesis explores the application of Tangible User Interfaces to Education. For this, a research study was conducted by building and testing a tangible-interactive game called Tangram Bridge. This Tangram based game was designed to teach players about basic physics principles such as balance, friction and motion on inclined planes.

The focus of this Tangram Bridge is middle school physics, and therefore concerns children aged 11 years and up, their instructors and care givers. This research also lays a lot of emphasis on constructive play amongst children.

Tangram Bridge is a versatile platform that can be scaled for younger or older populations. A comparative study of existing Tangible User Interfaces (TUIs) revealed opportunity spaces for this project. Through a compilation of related research in the fields of education, hands on learning, Tangible interaction and understanding play and learning amongst children, the constructionist views on learning are explored as

guidelines for the design of this study. Through the analysis of comparative research studies, trends on TUI with relation to education emerged, informing the design process for Tangram Bridge.

This research study discusses the application of Tangible user interfaces to education. It combines the research data collected through market research, user testing and literature reviews to explore the efficacy of TUI as teaching tool for abstract concepts that require imagination and experimentation.

The purpose of this research study is to test if Tangrams can be used as a physics-teaching tool. Through this project, I wanted to explore the application of Tangrams in physics classrooms as a tool to understand basic concepts of physics such as Inclined planes, friction, and balance.

To test this hypothesis, I developed an interactive Tangible User Interface (TUI) called Tangram Bridge. Tangram Bridge is in principle an augmented board game. Tangram Bridge comprised of physical Tangram pieces and a responsive touch surface. The objective of placing Tangram pieces in a virtual environment was to enable a richer, engaging hands-on learning experience.

Players needed to use simple concepts of physics such as friction, slopes and balance to create these bridges. The players understanding of these concepts would be tested by the merit of their bridge's design.

The interaction is based on the findings that Physical objects, like stones and pebbles, which children can touch and explore with their hands, help them to refine and stabilize the already acquired knowledge. Renowned pedagogues like Friedrich Froebel, Maria Montessori, Célestin Freinet and Jean Piaget have propagated this approach to physical bound teaching for a long time (Florian Scharf, 2008).

The first step in this process was to test and evaluate the design of Tangram Bridge. To this effect, an analogue precursor of Tangram Bridge was developed and tested as a board game. Conclusions from this study were used to improve and change the final design and user experience of the interactive board game.

Tangram Bridge uses traditional Tangram pieces to solve the various levels of the game. The various levels use a range of abilities, like understanding balance of forces, principles of inclined planes etc to solve the objective of the game. The objective of the game is to roll a ball from Point A on the game board to Point B. The only way this game differs from a traditional board game is that it is played on a slanted game board instead of a flat, horizontal one. The Tangram pieces are arranged on this slanted board to create a physical bridge between point A and point B. When the player builds a sound bridge between point A and point B, the ball rolls successfully to point B without dropping to the ground, player wins the round, and progresses to the next level. If the ball touches the ground without touching point B first, the game level start over and the player can arrange his pieces differently to build a better bridge.

Players need to use simple concepts of physics such as friction, slopes and balance to create these bridges. Once the player is finished creating his bridge, a ball is then rolled from point A to see if it reaches point B. Players may attempt each level of the game as many times as they like. There are multiple solutions to each level, and it is up to the player's imagination to use the constraints provided by the Tangram pieces to build a stable, working bridge between the two points.

The post test questionnaire will concentrate on gathering information about what the players thought of the game, its flaws, and document their learning from the game. Since the board game has been designed to emphasize on certain physical concepts, questions regarding players understanding of these concepts will be asked. These will be a set of short objective type questions. Conclusions from this study will be used to iterate on the next version of the game – Tangram Bridge

A Rough timeline has been presented to show expected progress of events through the course of thesis year.

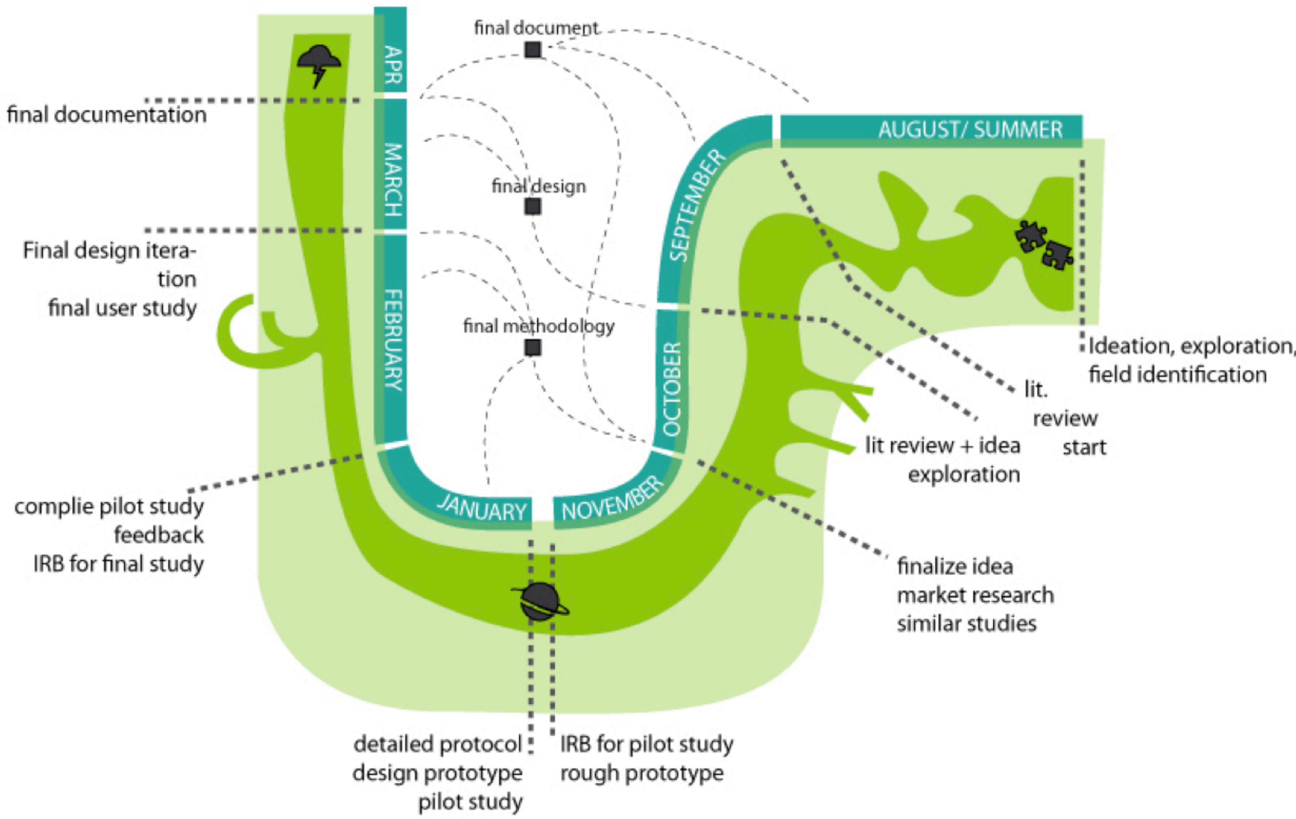


Figure 2 Timeline of Tangram Bridge project (Jain, 2010)

Through the analysis of comparative research studies, trends on TUI with relation to education emerged, informing the design process for Tangram Bridge.

This research study discusses the application of Tangible user interfaces to education. It combines the research data collected through market research, user testing and literature reviews to prove the efficacy of TUI s as teaching tool for concepts that require imagination and experimentation.

CHAPTER 1: INTRODUCTION

Background

“Play is often talked about as if it were a relief from serious learning. But for children, play is serious learning. Play is really the work of childhood.” -Fred Rogers

My starting point came from a personally felt cause: making learning more fruitful, relevant and engaging. As a starting point, I underlined by role, my belief system and my intent.

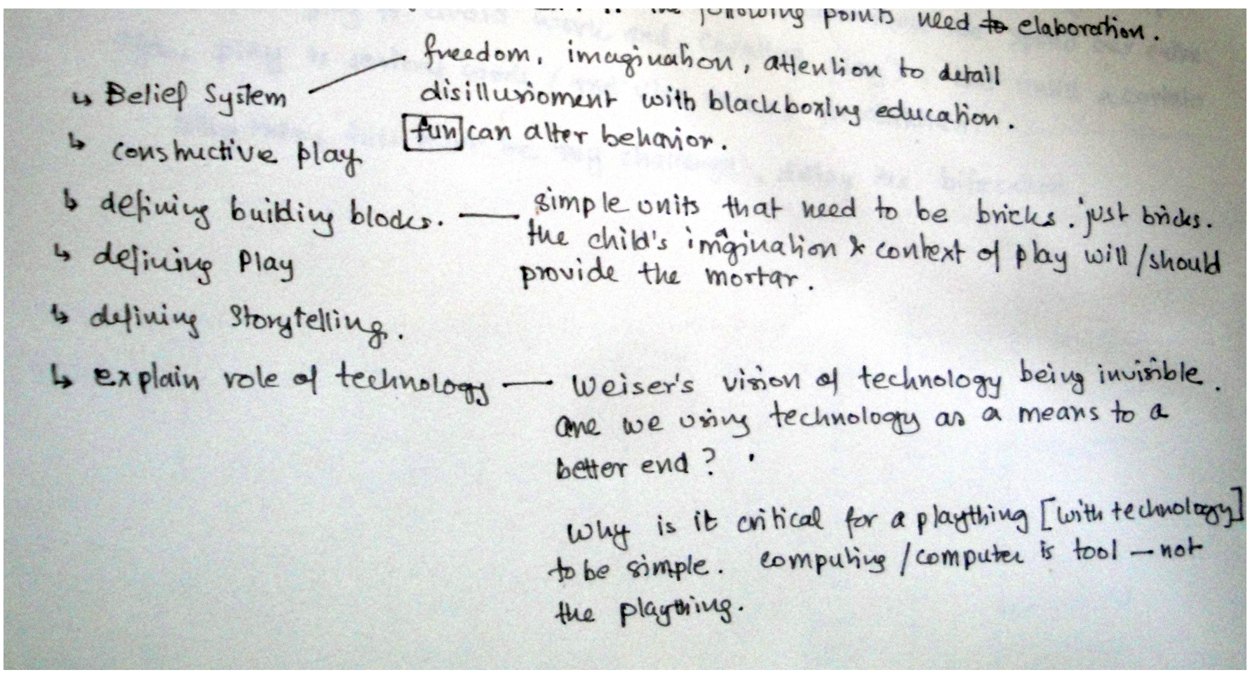


Figure 3 An outline of thesis objectives (Jain, 2010)

It is through play that much of children's learning is achieved. The physical, emotional and intellectual development of children is dependent upon active engagement - touching, manipulating, exploring and testing the world around them**Invalid source specified.**. Traditionally, physical objects and 'manipulatives' have been used in kindergartens, elementary schools and elsewhere to engage and help children learn in an effective and meaningful manner through hands-on play activity**Invalid source specified.**. However, as children progress through school, education becomes more literary, less hands on and more 'difficult'. Educational toys that provide hands-on and constructive learning have gained immense popularity in academic and commercial circles because of their value in childhood learning. In my present exploration, I begin by seeking a satisfactory answer to the question: *How can I improve the effectiveness of present educational experiences using physical/digital manipulative for young students?*

In the present day, the *adoption of technology* in educational practices, specifically those focused on early age education, is increasingly being seen as a major step forward in making the education 'modernized'. Unfortunately this adoption has just been limited to bringing the 'computer to the classroom' and making the students learn how to use it. Such a step has been consequently fraught with controversies, and not without reason - research over the years has shown that a child's active engagement with *physical objects* is essential for laying the foundation for intelligence and abstract thought amongst young children. Thus, the movement towards *virtual interfaces* cannot entirely be justified **Invalid source specified.**. The full potential of technological tools will only be achieved when they are used effectively and in ways that are meaningful and appropriate to support physical and critical thinking abilities of children. (Khandelwal). The diversity amongst children's learning styles creates a unique challenge. Can we design a toy that is universally appealing and effective?

Purpose of the study:

This project brings together a lot of disciplines. Some are more thoroughly chalked out than others, but they all contributed considerably to the design decisions through the project. Some of the main disciplines are Learning Sciences, Interaction design, Industrial Design and tangible User Interface design. Borrowing influences from these, I set out to synthesize a fun, engaging and learning experience for children of all ages. The device I proposed to design lends itself to multiple applications, and attempts to be a true constructionist means of learning.

Significance of the study: Learning Sciences:

Design for education: designing the experiences so as to enable people to do what they need to do (through inquiry) and thus learn in the process.

The major influence of learning Sciences was to be able to deconstruct learning, learning styles and instruction styles into categories, which enable me the cross-check my design against each type of use case scenario, and really ensure that my design works and benefits the widest range of users possible.

The other great influence was my theoretical introduction to Constructionism as a teaching style. Constructionism proposes that meaning constructed in the interplay of object and subject: When this theory is applied to learning, it translates to a learning system, where instruction is spare, rules and constraints are limited, and the learner is allowed to freely interact with the learning tool, constructing meaning through interaction, observation and empirical explorations. A typical example of such a learning tool would be construction blocks.

The Constructionist approach contends with the Instructionist approach, where the instructor transfers knowledge into the learner through information (as compared the learner's hands on experience with problem at hand). This method of knowledge generation is widely used in schools, where teachers address an entire classroom of students, instructing them with pre-existing models of knowledge, training the learner to accept and use a set of cognitive assumptions his or her mind makes through these instructions. This learning methodology is efficient in terms of time and number of students 'taught', but does little to spark a child curiosity and an appreciation of scientific inquiry into the nature of things.

The largest overarching benefit of constructionist toys is its ability to creating a sense of autonomy and self-responsibility for exploration and learning. Autonomy of study is fueled by curiosity, thus making the learning Endeavour personally meaningful. This can be a crucial step for every child, as a culture of instilling inquiry and self-exploration creates a personality that learns by experimentation as much as by hands on learning.

Creating one's owns mental models can be a critical skill for problem solving and innovation.

Children are naturally curious and hands on. These natural tendencies could easily be leveraged using a tool that does not demand too many rules be followed, lends itself to a child's abstract thought yet gently instills a curiosity that begets constant exploration and iterative learning.

Information collected in this manner creates confidence, and then, if this information is shared, it is reinforced in memory, becoming knowledge, facilitating a strong foundation of creating one's owns mental models.

Problem Identification:

At the heart of this project, lie some of the most basic problems that plague our education systems:

Intimidation by information: so much so as to dwarf learning capacity, natural curiosity and pursuit of knowledge

Borrowing assumptions of teacher: Inability to understand the basic leads to 'parroting; of a teachers words, concepts, even mental models. A teacher's position naturally evokes respect, and trust, paralyzing a learner's ability to question his or her learning. We need to prevent students from settling into the habit of borrowing assumptions about the world.

Telling someone they are wrong: Unfortunately, we see mistake as ugly, unlucky outcomes of wrong method, application. We constantly discount mistakes as errors, unwanted wastes of resources, be it time, effort, money, or education. Mistakes are crucial; they build our repertoire of experiences with critical information on *what makes a right.* One of the most frequently occurring bad learning experiences for learners is being told they're wrong (instead of they are not there yet). Mistakes are part of the learning process, and we need to design more and more tools that encourage a students to learn from mistakes them and iteratively approach an optimum learning.

Learning Styles:

It is widely recognized that each person prefers different learning styles and techniques. Learning styles group common ways in which people learn. Everyone has a mix of learning styles. Yet, each one of us may have a dominant style of learning. By using this style, we retain information better and for longer. These learning styles are largely based on our senses and our ability to assimilate data. The various Learning styles have been identified as:

The learning styles are:

1. Visual (spatial). Prefer using pictures, images, and spatial understanding.
2. Aural (auditory-musical). Prefer using sound and music.
3. Verbal (linguistic). Prefer using words, both in speech and writing.
4. Physical (kinesthetic). Prefer using your body, hands and sense of touch.
5. Logical (mathematical). Prefer using logic, reasoning and systems.
6. Social (interpersonal). Prefer to learn in groups or with other people.
7. Solitary (intrapersonal). You prefer to work alone and use self-study

Using multiple learning styles and “multiple intelligences” for learning is a relatively new approach. This approach is one that educators have only recently started to recognize. Traditional schooling used (and continues to use) mainly linguistic and logical teaching methods. It also uses a limited range of learning and teaching techniques. Traditionally, schools rely on classroom and book-based teaching, repetition, and pressured exams for reinforcement and review. A natural result of this is the segregation of learners into “bright” and “dumb” students, depending on whether their natural learning styles match those being practiced and encouraged at school.

By recognizing and understanding the various learning styles, I am attempting to create a learning tool that facilitates multiple learning styles.

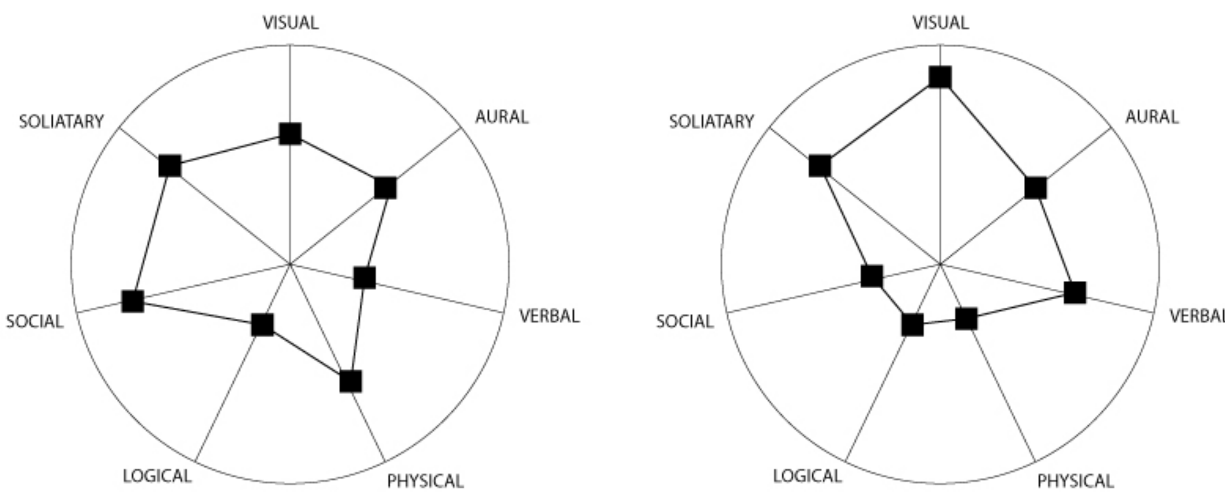


Figure 4 Sample Memletics Learning style graph, mapping learning styles of two individuals (Overview of Learning Styles)

Epistemological Pluralism:

The ideal typical hard and soft approaches are each characterized by a cluster of attributes. Some involve organization of work (some prefer abstract thinking and systematic planning; others prefer a negotiation based approach and concrete forms of reasoning); other attributes concern the kind of relationship that the subject forms with computational objects. Hard mastery is characterized by a distanced stance, soft mastery by closeness to objects.

Could this be applicable to tangible learning style?

So for example, closeness to objects tends to support a concrete style of reasoning, a preference for using objects to think with, and a bias against the abstract formulae that maintain reason at a distance from its objects. Conversely, a distanced relationship with objects supports an analytic, rule- and plan-oriented style. Our theoretical conjecture is that degree of closeness to objects has developmental primacy; it comes first. The child forms a proximal or distant relationship to the world of things. The tendency to use the abstract and analytic or concrete and negotiation based style of thinking follows.(Seymour Papert)

Computational objects offer a great deal to those whose approach requires a close relationship to an object experienced as tactile and concrete. Computational objects offer a physical path of access to the world of formal systems. Some people are comfortable with mathematical experiences that

manipulate symbols on quadrille- ruled paper. But for many the ambivalent nature of computational objects means quite simply a first access to mathematics.

CHAPTER 2 : SURVEY OF LITERATURE:

This project is based on assumptions about learning theory, and role of toys in learning and exploration. These assumptions are verified through the survey of literature on work previously done in this field. This exercise also provides a basic design guideline structure for the next step: building a new learning tool.

The basic assumptions that will be verified through this survey are:

1. Children learn through physical manipulation
2. Physical manipulation is better achieved through tangible artifacts
3. Tangible interaction supports better learning
4. Richer the tangible interaction, richer the learning
5. Building blocks are a good tool to create new mental models
6. Children create mental model through unique learning senses, therefore a multi sensorial learning tool is ideal for effective learning.
7. Interactivity can enhance engagement, tangible manipulation enhances learning therefore tangible user interface can be used for effective learning

A wide range of literature was surveyed in this regard, and I have outlined some of my primary influences to help the reader understand an over arching structure of the exercise.

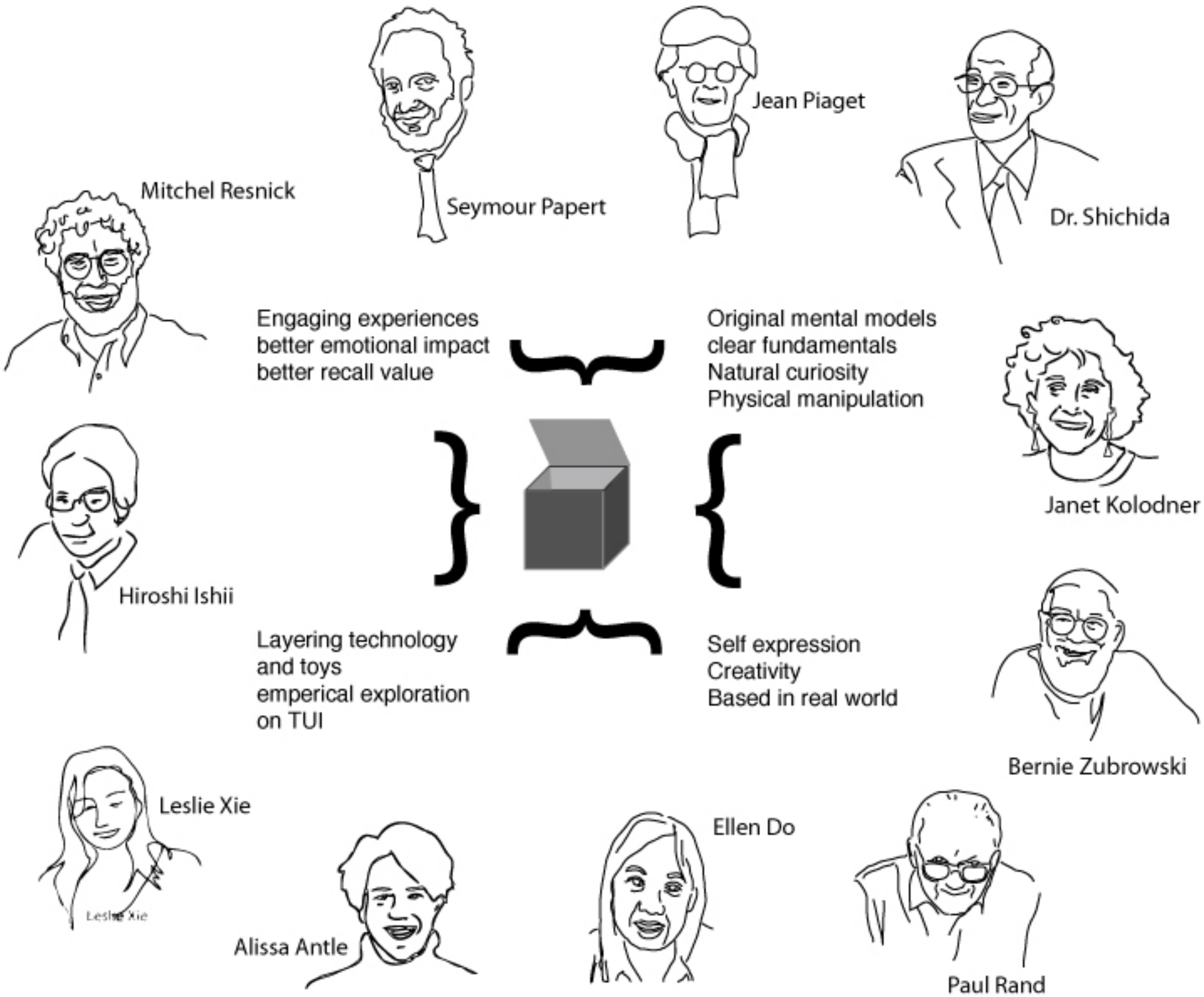


Figure 5 mapping important influences in relevant field of work (Jain, 2010)

Why we need to go back to the basics, and how:

In his paper: All I Really Need to Know (About Creative Thinking) I Learned (By Studying How Children Learn) in Kindergarten, Resnick talks about a five step cycle that he calls the “kindergarten approach to learning.”

Imagine, Create, Play, Share, Reflect, and back to Imagine:

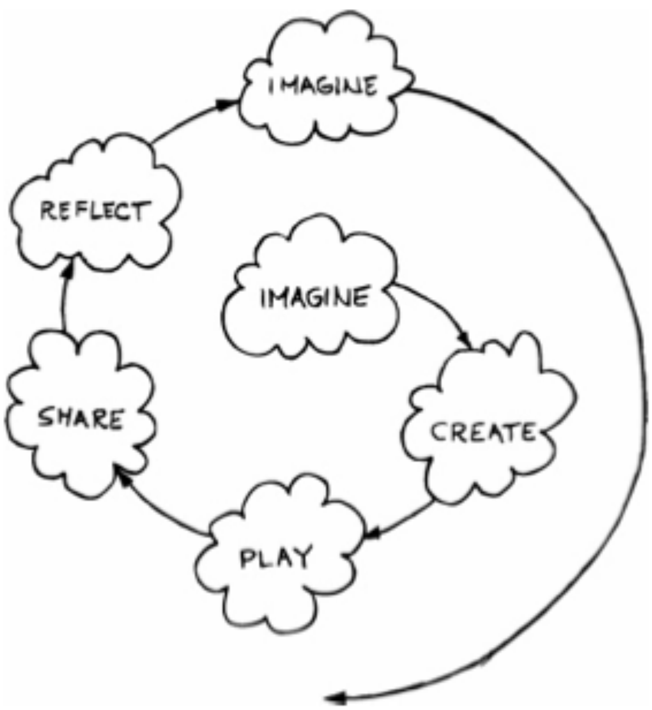


Figure 6: The Kindergarten approach to learning. (Resnick)

Learning through hands-on manipulation of physical manipulatives may be beneficial (e.g., Montessori Method, Frobel’s Gifts). However, there is little empirical evidence to date to support such claims in the realm of children’s tangible computing (Antle A. , 2007),(Marshall P. , 2007). Understanding the role that the hands play in supporting certain mental processes can help guide design decisions about how to choose an input method and design representations for a particular activity. Studying how children use their hands to augment developing cognitive abilities provides a window on physical interaction and may highlight results that can be generalized to adult populations.

There is a benefit to supporting physical actions on computational objects, which can make difficult mental tasks easier to perform.(Antle A.N, 2009)

Figure 7 Frobel's gifts (Montessoritoys)

Frederick Froebel’s Kindergarten provides an early and important instance of specialized objects in education. Froebel distilled his world view into a number of kindergarten “gifts,” physical objects that children used in daily lessons to learn about common forms and processes found in nature. The kindergarten gifts had a deep influence on 20th c. art. For instance, Frank Lloyd Wright credited kindergarten as the basis for his aesthetic vocabulary, and many of his architectural forms are similar to artifacts from the kindergarten classroom. Similarly, all of the founder of the Bauhaus either attended or taught kindergarten [Brosterman 1997]. Such evidence shows the strong influence educational objects can have on children's aesthetic development.

Physical materials can also help children develop skills manipulating abstract concepts. Educational manipulatives are toys that are specially designed to help children with this. For example, "Cuisinaire rods" allow children to explore the abstract concepts of arithmetic by manipulating concrete, physical blocks of different lengths. By arranging blocks to create series of equal length, children can discover that 1+3=2+2.(Raffle, 2006)

The Kindergarten methodology:

Resnick expands on how, if older students are to learn through the kindergarten approach, they need different types of tools, media and materials. He then goes on to build guidelines such as the materials do not over-constrain or over-determine. Children with different interests and different learning styles can all use the same materials, but each in his or her own personal way.

Resnick advocates we provide children with the opportunity to design their own games. In her book Minds in Play, Yasmin Kafai documents how elementary-school students become more creative thinkers as they design their own games. His research group teamed up with Kafai to develop a new programming language, called Scratch (http://scratch.mit.edu), that enables children to create not only games but also interactive stories, animations, music, and art . In designing Scratch, one of the key goals was —tinker-ability – that is, make it easy for children to playfully put together fragments of computer programs, try them out, take them apart, and recombine them. To create programs in Scratch, you simply snap together graphical blocks, much like LEGO bricks or puzzle pieces.(Resnick M. , All I Really Need to Know (About Creative Thinking) I Learned (By Studying How Children Learn) in Kindergarten*)

The value of using the hands to manipulate objects in problem solving is not necessarily confined to direct input methods. Thinking with Hands -- Complementary Actions

Figure 8 children problem solve through direct physical manipulation. (Lesley Xie,2008)

An individual or group of individuals can improve their cognitive strategies for solving a problem by adapting the environment. One of the ways individuals do this is through a complementary strategy. Kirsh defines a complementary strategy as any organizing activity, which recruits external elements to reduce cognitive loads(Kirsh D. , 1995). A complementary action can be recognized as an interleaved sequence of mental and physical actions that result in a problem being solved in a more efficient way than if only mental or physical operations had been used. Complementary strategies involve actions, which can be either pragmatic or epistemic: Epistemic actions are those actions used to change the world in order to simplify the problem-solving task; pragmatic actions are those actions whose primary function is to bring the individual closer to his or her physical goal (e.g., winning the game, solving the puzzle, finding a solution).(Antle A.N, 2009)

An action can serve both epistemic and pragmatic purposes simultaneously. For. E.g. In the realm of jigsaw puzzles, players typically organize pieces into groups containing: corner pieces, edge pieces, same colored pieces, or pieces of similar shape. These intermediate steps support visual search, but their function is epistemic, in that they do not bring players physically closer to their pragmatic goal of placing pieces to complete the puzzle (Kirsh D. a., 1994)

Understanding why constructionism is critical:

Friedrich Fröbel: A German pedagogue, laid the foundation for modern education based on the recognition that children have unique needs and capabilities. He developed the concept of the “kindergarten”. Frobel’s gifts, a set of construction blocks used to date in Kindergarten enables children to put their own thoughts to work. Frobel’s work can be viewed as an early example of Seymour Papert’s constructionist approach to education(Shade D. (., 1996) , which aims to engage learners in personally meaningful learning experiences.

Seymour Papert: A mathematician, computer scientist and artificial intelligence pioneer, Dr. Papert worked with Jean Piaget. He created the LEGO programming language and is recognized as the father of Educational Computing. People laughed at Seymour Papert in the sixties when he talked about children using computers as instruments for learning and for enhancing creativity. The idea of an inexpensive personal computer was then science fiction. But Papert was conducting serious research in his capacity as a professor at MIT. This research led to many firsts. It was in his laboratory that children first had the chance to use the computer to write and to make graphics. The Logo programming language was created there, as were the first children's toys with built-in computation. The Logo Foundation was created to inform people about Logo and to support them in their use of Logo-based software for learning and teaching.

Today Papert is considered the world's foremost expert on how technology can provide new ways to learn. (papert.org)

Mitchel Resnick: Cricket technology, Mindstorms created by LEGO Our guiding principle is “many paths, many styles” – that is, to develop technologies that can be used along many different paths, by children with many different styles. Too often, educational technologies are overly constrained, such as tutoring software for teaching algebra, or simulation software for modeling planetary motion in the solar system. Our goal is to provide tools that can be used in multiple ways, leaving more room for children‘s imaginations.(Resnick M. , All I Really Need to Know (About Creative Thinking) I Learned (By Studying How Children Learn) in Kindergarten*)

Meaning is created through restructuring the spatial configuration of elements in the environment. A highly structured environment does not provide opportunities for restructuring and thus limits knowledge construction. What is required is an environment, either computational or otherwise, that supports multiple spatial configurations.(Antle A. n., 2009)

Applying Constructionism to Education:

Resnick, through his research studies with children and toys, compiled a list of guidelines for designing construction kits for kids: (Resnick M. , Some Reflections on Designing Construction Kits for Kids)

1. Design for Designers
2. Low Floor and wide Walls *
3. Make Powerful Ideas Salient – Not Forced

4. Support Many Paths, Many Styles
5. Make it as Simple as Possible – and Maybe Even Simpler
6. Choose Black Boxes Carefully
7. A Little Bit of Programming Goes a Long Way
8. Give People What They Want – Not What They Ask For
9. Invent Things That You Would Want to Use Yourself
10. Iterate, Iterate – then Iterate Again

* Analogy with LEGO kits: low starting level + wide range applications vs. get started (low floor) and possible for experts to work on increasingly sophisticated projects (high ceiling). For construction kits: diversity of outcomes as an indicator of success.

On using Technology for Education:

Mitchel Resnick , a professor at MIT media lab founded a research group has developed a variety of educational tools that engage people in new types of design activities and learning experiences, including the "programmable bricks" that were the basis for the award-winning LEGO Mindstorms and starLOGO software. Certain excerpts from his paper simply discuss ideas on how children engage in learning and hw we can empower them with tools. Mitchel Resnick is a “constructionist” learning theorist and believes that ideas, and concepts are something that a child needs to build on his own, to understand his world better, and our jobs as educator is to enable this query through the right tools, not instruction.(Resnick M. , All I Really Need to Know (About Creative Thinking) I Learned (By Studying How Children Learn) in Kindergarten*)

Resnick talks about how constructionism is critical to education for every child, as our current instruction system fixates itself on a centralized mindset (Resnick M. , Beyond the Centralized mindset: Starlogo and Netlogo) : “Constructivists might be happier with the "from scratch" modeling activity, as it requires the learner to start where she is at and interact with the modeling primitives to construct a model of the phenomenon. That special breed of constructivist called constructionists (Papert, 1991) would argue that this externalized construction process is the ideal way to engage learners in constructing robust mental models. The learner is actively engaged in formulating a question, formulating tentative answers to her question and through an iterative process of reformulation and debugging, arriving at a theory of how to answer the question instantiated in the model.

This process is an act of doing and constructing mathematics and science instead of viewing the results of an expert having done the mathematics and science and handing it off to the learner. On the epistemological side, this lesson that mathematics and science are ongoing activities in which ordinary learners can be creative participants is an important meta-lesson of the modeling activity.”

This prevalence of ‘computation’ as we understand in the classical sense of a computer also needs to tie in with our previously discussed concept of Epistemological Pluralism(Seymour Papert)

Since the prevailing image of the computer is that of a logical machine, and since programming is seen as a technical and mathematical activity, the existence of anything but an analytic approach in this area makes a dramatic argument for pluralism.(Seymour Papert)

"it would be particularly oxymoronic to convey the idea of constructionism through a definition since, after all, constructionism boils down to demanding that everything be understood by being constructed" (Papert, 1991)

"Constructionism might be be understood by educators trained in the Piagetian tradition as a constructivist approach to developing and evaluating educational programs that make use of technologies with the purpose of learning. Constructionism proposes that technologies, computers as well as tangible manipulative such as robotics, are powerful for educational purposes when used for supporting the design, the construction, and the programming of personally and epistemologically meaningful projects (papert, 1980; resnick, bruckman & martin, 1996a)

Early childhood education has had a rich tradition of learning manipulatives. Papert's constructionism is rooted in Piaget's constructivism, in which learning is best categorized as an individual cognitive process given a social and cultural context. While one concentrates on the theory of how knowledge is built in individuals, the other seeks wide based applications for itself as a principle. Thus constructionism is both a theory of learning and a strategy for education.

it offers a rich design based learning environment in which learning happens best when children and adults are engaged in learning by making, creating, programming, discovering and designing their own " objects to think with" in a playful manner." (bers: block to robots)

Various constructionist tools have been developed to reflect the ideal learning environment, some explicitly for math, science storytelling, languages etc. others more generic, which accommodate interpretation and actively support transfer of knowledge. Bers talks about cleaving constructionism into four basic tenets:(Marina U. Bers, 2002)

1. Learning by design
2. Objects to learn with
3. Powerful ideas
4. The premium of self-reflection.

In this context, teachers are asked to design a learning environment to support children in their explorations, to scaffold learning, and to provide interesting materials for children to manipulate in order to make concrete projects to share with others in the community (Bers & Urrea, 2000). These ideas are the core of constructionism, which has focused on designing computational learning environments that support all of the tenets. For example, to support children's explorations, computational environments must provide tools for learners to become designers of their own projects. As Mitchel Resnick pointed out, children's interactions with technology should be more like finger painting than watching television (Resnick, 2000).

Programmers and developers of these environments need to strike the right balance between enabling children to "translate" their ideas into real products, but also guide them into a happy understanding of how limitations and rules shape a real world product. It would be a wrong and unhelpful to follow a learning process that only facilitates success and masks failure.

Children might have wonderful ideas. However, their understanding of the technology and their skills might be limiting to the implementation of these ideas. (Bers, 2008)

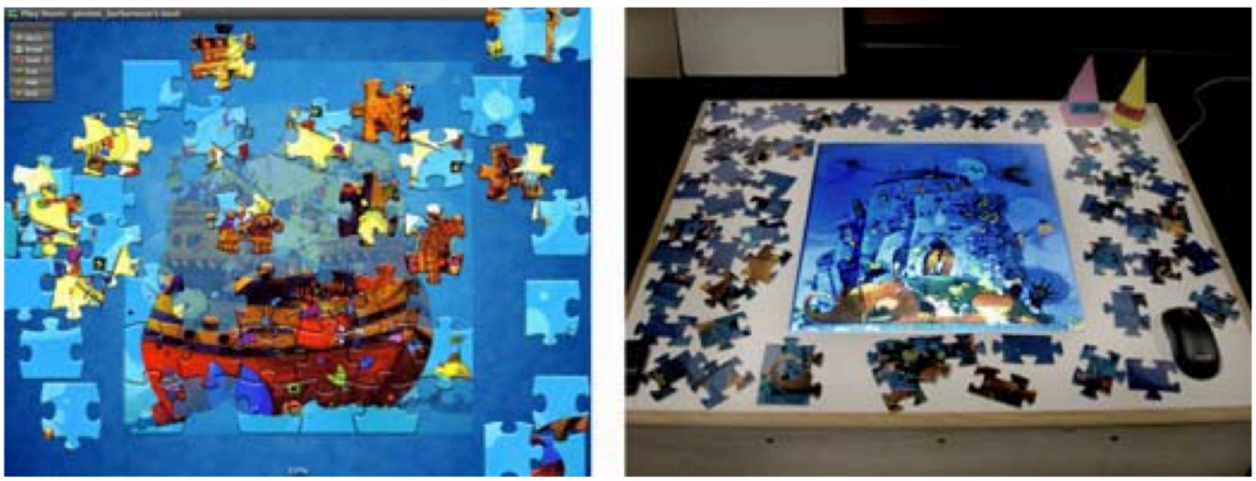


Figure 9 GUI (left) and TUI (right) puzzles. Antle's work looks at comparing different input media to compare enjoyment and engagement. (Lesley Xie, 2008)

Some of the questions that we need to ask ourselves in the purview of technology in education might be: Does supporting users to manually handle augmented physical objects change how they problem solve? How can we design interfaces to support children to offload difficult mental tasks to physical interactions with environment through using their hands? Does physical or digital manipulation take longer? If it takes longer does this mean it is harder? Does direct physical interaction allow more opportunities for actions which support task learning?((Antle A.N, 2009)

Why moderating constructionism is key:

Seymour Papert talks about how its difficult to define constructionism without being an Instructionist, because constructionism would require that each reader 'create' his own mental definition of the word, and it never be transmitted through a ' pipeline' of instruction. He then compares it to recursive functions and how each time the loop expresses itself; it defines itself a little bit more.(Papert, 1991)

Physical Activity: making cognition and action work together:

Children exploit physical action to dynamically offload parts of mental operations to physical action in the environment. Cognitive performance is enhanced through physical strategies that simplify the cognitive aspects of task. For example, in solving a jigsaw puzzle, a child will typically offload some of the difficult task of visualizing puzzle pieces by rotating the pieces with her hands and making spatial comparisons. Children solve many types of problems through this type of tight coupling of mental operations with physical actions in the environment. As they physically manipulate objects, they also learn to manipulate mental models of the world. In doing so, they can successfully tackle problems that require mental abilities they are still developing and concurrently develop the requisite skills.(Antle A. n., 2009)

Figure 10 A child physically manipulates objects to assist better cognition; grouping, rotating and sorting helps her move forward with the puzzle problem. (Antle A.n., 2009)

What role do Tangible interactions play in learning?

Physical activity and playing with physical objects such as building blocks and jigsaw puzzles play an important role in the development of children. In the beginning of the 20th century, Montessori (Montessori, 1919) advocated self-directed learning through the use of physical manipulatives. It is observed that children were able to easily engage in play and concentrated learning with physical objects.

Decades before digital technologies became accepted in everyday use, psychologists sought to understand the benefits of using physical objects and physical activity for learning. Bruner (Bruner, 1996) extensively worked together with the influential learning-psychologist Piaget, provided evidence that children often start learning how to solve problems by using physical materials. In this process, children combine three different ‘modes of knowing’: action, image and symbol (Bruner, 1996). For example when learning about volume by pouring water from a thin glass into a wide glass, the action of pouring water is combined with the image of the water in both glasses which eventually leads to a symbolic representation of the concept of volume. Bruner states that forcing a combination of the three modes of knowing can result in a powerful representation of the world. The power of combining action, image and symbol is also underlined by experiments reported by for example Rieser et al. (Rieser, 1994) showing that physical action can support remembering, spatial imagery and imagining different perspectives of the surroundings.

Similar influential learning theories are those of psychologists Vygotsky and Gal’perin, described in (Parreren, 1972). These theories emphasize that “mental acts origin in material acts”. In other words, higher psychological functions such as logical thinking and memory can only develop through physical acts such as manipulating physical objects.

Marshall et al. (Marshall P. P., 2003) build on this while focusing on technology enhanced tangible objects for learning. Adopted from Heidegger(Heidegger, 1996), they distinguish tangibles to be used either as ‘ready-to-hand’ or ‘present-at-hand’. Objects are ready-to-hand when they are used to accomplish a task; the user is focused on the task rather then on the object or tool. Objects are present-at-hand when the user focuses on the object itself, which allows reflecting on the activity. Marshall et al. (Marshall P. P., 2003) suggest that effective and productive learning should involve both ready-to-hand and present-at-hand usage of objects; this allows the child to frequently reflect on the learning activity, which is needed to learn from the experience. They suggest that tangible interfaces can be very effective for learning when they allow children to alternate between these two ways of treating objects. Learning takes places when shifting between experience (e.g., actions, material acts) and reflection (e.g., symbols, mental acts). (Bakker S., 2009)

By embedding computational power in traditional children's toys such as blocks, beads, and balls, young children can learn about dynamic processes and "systems concepts ", such as feedback and emergence, that were previously considered too advanced for them (Resnick, 1998; Resnick, Berg, & Eisenberg, 2000).

It is within this tradition that robotics presents a wonderful opportunity to introduce children to the world of technology. Not only can children de- sign and build interactive artifacts using materials from the world of engineering, such as gears, motors, and sensors, but they are also encouraged to integrate art materials and everyday objects to make their projects aesthetically pleasant.(Marina U. Bers, 2002)

Tangible artifacts facilitate embodiment. Embodiment means how the form of its physical manifestation in the world shapes the nature of a living entity's cognition. An embodied perspective on human cognition foregrounds the role of the body, physical activity, and lived experience in cognition. Put simply, embodied cognition emphasizes how the particulars of human bodies acting in complex physical, social, and cultural environments determine perceptual and cognitive structures, processes, and operations.(Antle A. n., 2009)

A child's experiences with spatial structure later give meaning to the symbolic representations used in arithmetic. Children develop new understandings of many phenomena in this way. Children can test hypotheses, generate new states of information, and actively construct new knowledge in the world by manipulating its spatial properties.(Antle A. n., 2009)

The Tangible Advantage in Abstract Domains

Abstract concepts are hard to learn. The advantage of tangible interfaces as a teaching tool for abstract problem domains is threefold:

(1) Sensory engagement – the natural way children learn, engaging multiple senses (in this case touch, vision, auditory) in a constructive process.

(2) Accessibility – dramatically improves accessibility to younger children, to people with learning disabilities, and to novices.

(3) Group learning – provides a multi-hand interface, does not give the control to one person, facilitates natural group interaction, and promotes group discussion.

Physical objects have been traditionally used in kindergartens and elementary schools to introduce young learners to abstract concepts such as quantity, numbers, base ten, fractions etc. Abstract concepts of dynamic behavior, involving change and behavior over time, make the learning challenge even harder.(Oren Zuckerman S. A., 2005)

A ten-year-old girl said: “I am a person that likes to do things with my hands. With software on the computer, it’s always just clicking buttons and inserting numbers and then a window opens and you see the result. With the blocks I can feel what I’m doing, I can see the flow.”(Oren Zuckerman S. A., 2005)

What is Tangible User interface?

Tangible user interfaces utilize physical representation, manipulation of digital data and offer interactive couplings of physical artifacts with computationally modified digital information(E. Hornecker, 2006)

Price et al. report that interaction with tangibles encourages engagement, excitement and collaboration(S Price, 2003)

Eva Hornecker and Jacob Buur (Eva Hornecker, 2006)present a conceptual model that lets us understand and sort tangible User interfaces through the kind of interactions they facilitate. The definition of ‘tangible interfaces’ frequently used in HCI is too narrow to encompass these. From the characterizations found in literature, we can distinguish a data-centered view, pursued in Computer Science and HCI; an expressive-movement-centered view from Industrial and Product Design; and a space-centered view influenced from Arts and Architecture:(E. Hornecker, 2006)

1. Data-centered view: Ullmer and Ishii and others in HCI (Dourish, 2001), (Holmquist L. E., 1999), (Ullmer B. and Ishii, 2001) define ‘tangible user interfaces’ as utilizing physical representation and manipulation of digital data, offering interactive couplings of physical artifacts with “computationally mediated digital information”(Holmquist L. E., 1999). This characterization of tangible interfaces is frequently cited in HCI publications. Conceptual research from HCI and computer science often explores possible types of coupling and representations (Ullmer B. and Ishii, 2001). A variant of this view explores different types of couplings and transversals between the digital and the physical [26].

2. Expressive-Movement-centered view: An emerging ‘school’ in product design aims to go beyond form and appearance and to design the interaction itself. This view emphasizes bodily interaction with objects, exploiting the “sensory richness and action potential of physical objects”, so that “meaning is created in the interaction”(Djajadiningrat, 2002). Design takes account of embodied skills, focuses on expressive movement and ‘rich’ interaction with ‘strong specific’ products tailored to a domain (Buur, 2004), (Jensen, 2005). The design community prefers the term ‘tangible interaction’.

3. Space-centered view: Interactive arts and architecture increasingly talk about ‘interactive spaces’ and build installations based on spatial interaction. ‘Interactive/ interactivating spaces’ rely on combining physical space and objects with digital displays or sound installations (Bongers, 2002), (Rubidge, 2004). “Interactive systems, physically embedded within real spaces, offer opportunities for interacting with tangible devices”, and so “trigger display of digital content or reactive behaviors” (Ciolfi, 2004). Full-body interaction and use of the body as interaction device and display are further typical characteristics of this approach.

Tangible interaction, as we understand it, encompasses a broad range of systems and interfaces, building upon and synthesizing these views. These share the following characteristics: tangibility and materiality, physical embodiment of data, embodied interaction and bodily movement as an essential part of interaction, and embeddedness in real space [4, 5, 6, 8, 9, 18, 34]. Tangible interaction encompasses approaches from HCI, computer science, product design and interactive arts.

This concept of tangible interaction has a broader scope than Ullmer and Ishii's description of tangible interfaces: "giving physical form to digital information" and its subsequent physical control [34], which is often used as a definition of TUIs (data-centered view). Tangible interaction is not restricted to controlling digital data and includes tangible appliances or remote control of the real world [24]. This approach focuses on designing the interaction itself (instead of the interface) and on exploiting the richness of bodily movement [5, 8]. Interaction with 'interactive spaces' by walking on sensing floors or by simply moving in space [4, 28] further extends our perspective on 'tangible' interaction, the body itself becoming an input 'device'. Instead of using a restrictive definition that excludes some of these interesting system variants (often crossing categories, e.g. [28]),

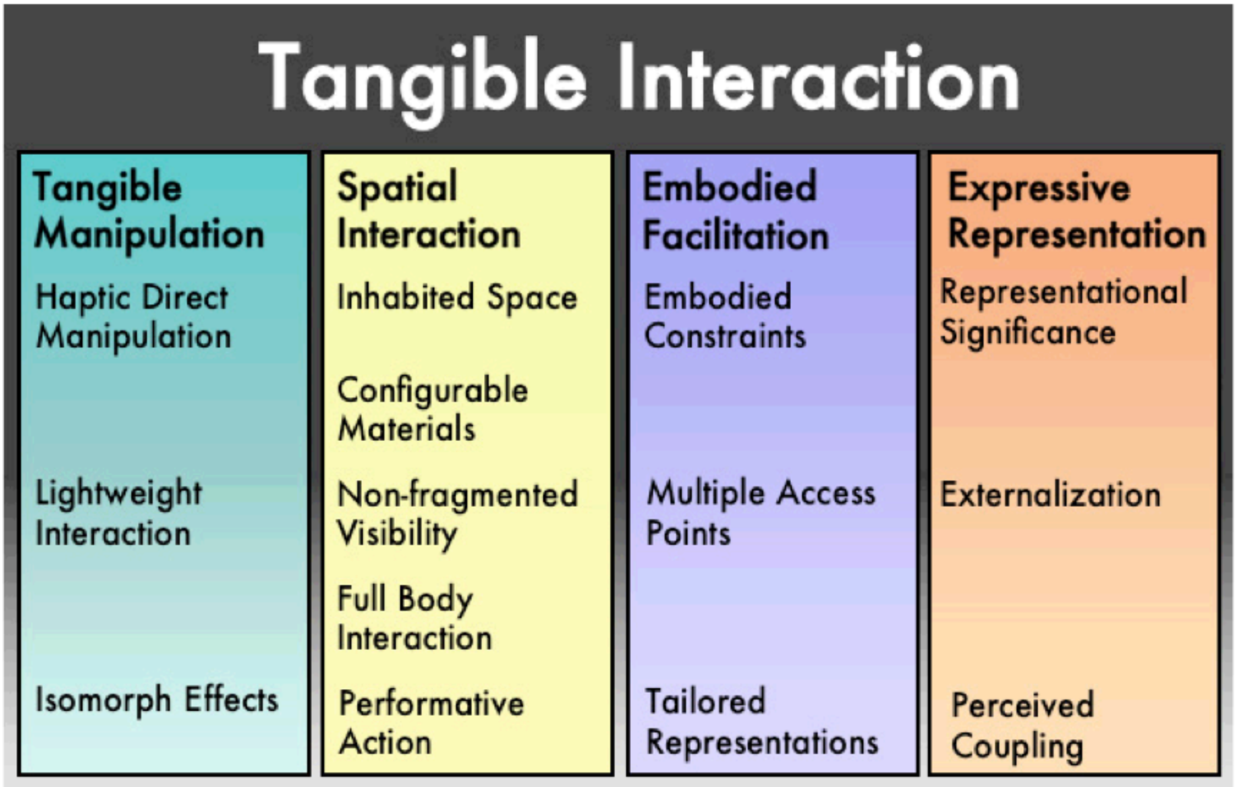


Figure 11 Tangible Interaction Framework with themes and concepts. (Eva Hornecker, 2006)

The framework is structured around four themes (figure 3) that are not mutually exclusive, but interrelated, offering different perspectives on tangible interaction. A set of concepts elaborates each theme, providing more concrete handles for understanding their implications. Themes are:

1. **Tangible Manipulation** refers to the material representations with distinct tactile qualities, which are typically physically manipulated in tangible interaction.

2. **Spatial Interaction** refers to the fact that tangible interaction is embedded in real space and interaction therefore occurs by movement in space.

3. **Embodied Facilitation** highlights how the configuration of material objects and space affects and directs emerging group behavior.

4. **Expressive Representation** focuses on the material and digital representations employed by tangible interaction systems, their expressiveness and legibility.

Do tangible interfaces enhance learning?

Paul Marshall looks at the area of learning with tangible interfaces, suggesting that more empirically grounded research is needed to guide development. This interest is related to the more general view within education that hands-on activity or manipulation of physical manipulatives can be of particular educational benefit Most work in this area too has focused on technical development; theory and empirical demonstrations of the utility of tangible interfaces for learning have been less forthcoming. This has led to a situation where designers of learning environments have little principled basis on which to decide whether a tangible interface will be suitable for a particular task, which of the many types might be most appropriate, what features of a tangible interface design might be associated with particular benefits to interaction or learning and what features might be more incidental.

A growing body of literature within the cognitive sciences focusing on embodiment suggests stronger links between physical activity and cognition than had previously been described (Barsalou L. a.-H., 2005), (Lakoff, 1999)This work suggests that abstract thought might be grounded in and built on top of sensory- motor systems.

Physical activity has been shown to influence and constrain cognitive processes (Barsalou L. N.). A second body of research within education and psychology has emphasized the role of physical materials and manipulatives in supporting learning (Montessori, The Montessori method: scientific pedagogy as applied to child education in the "children's houses"., 1912). Together, this work points to the potential of tangible systems in supporting learning.

Where tangible interfaces are used to promote an activity like learning, Marshall suggests that a more empirically grounded framework is necessary to facilitate design.

Marshall developed and presented an analytic framework comprising of six perspectives that might guide research and development on the use of tangible interfaces for learning.

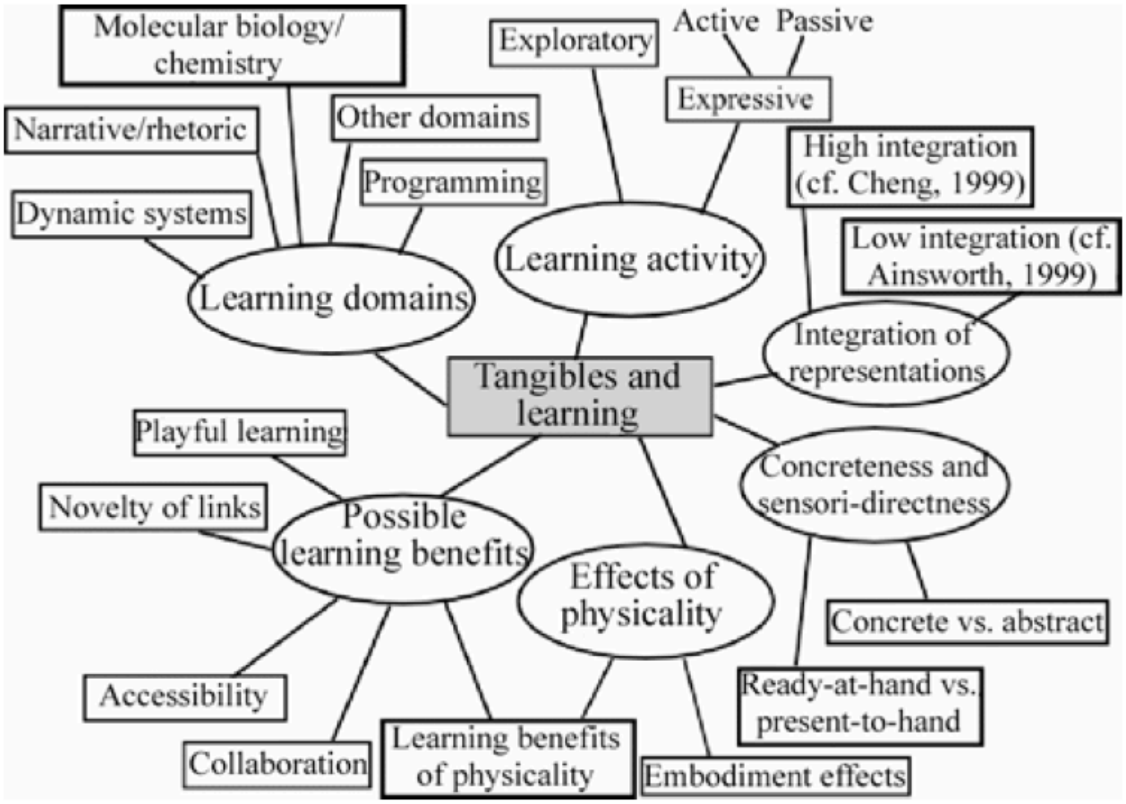


Figure 12 Analytic framework on tangibles for learning (Marshall P. , 2007)

With the introduction of pervasive technologies, new opportunities for encouraging physical activity and using physical objects in learning have emerged. Recent studies underline the benefits of Embodied Interaction (Dourish, 2001)and Tangible User Interfaces (TUIs) (Ullmer B. and Ishii, 2001)for learning (e.g. (Marshall P. P., 2003)and (Parreren, 1972)). Antle (Antle A. , 2007) argues that tangible systems should be very powerful in engaging children in active learning; body movement and touching and manipulating the real world are valuable for cognitive development. Zuckerman et al. (Zuckerman, 2005)argue that TUIs are particularly beneficial for learning in abstract problem domains such as mathematics, as they promote sensory engagement; using multiple senses is the natural way for children to learn. O'Malley and Stanton-Fraser (O'Malley) state that manipulating physical objects encourage self-directed activity in children. Therefore, tangible interaction can be valuable for learning and new technologies offer opportunities to bringing playfulness back into learning.(Bakker S., 2009)

Comparing medium of learning:

As of 2008, it was still unknown how the properties of tangible interactions will contribute to the enjoyment and engagement in tangible games for school age children. Understanding these issues would contribute to grounding this technology agenda in empirical studies; inform the development of stronger frameworks for the theory and proactive of play based learning with tangibles; and lead to the development of principles to guide the design of new form of tangibles.(Lesley Xie, 2008)

Leslie Xie and Alissa Antle looked at developing this metric through an experiment aimed at children aged 7 - 12 yrs. this experiment was the first empirical comparison of physical (traditional), graphical and tangible user interfaces for school aged children.

African et al. describe the design and implementation of Ely, a tangible tabletop environment, which supports school aged children's collaboration (Diana Africano).

Figure 13 Ely: Touch screen, knobs and RFID readers. The interface presents one shared and three personal areas (Diana Africano)

McNerny suggests that compared to screen based user interfaces, tangible user interfaces have made computation immediate and more accessible, and that they are appropriate for children learning about computation and scientific exploration (McNearny, 2004). Fernaues and Tholander propose that tangibles are good resources for action as well as alternative forms of data representation (Y fernaeus, 2006). Bohn present s a smart jigsaw puzzle but provides no systematic evaluation (5)

Enjoyment and Engagement:

Enjoyment and engagement are integral and critical to children's playful learning experience. The conceptual definition of enjoyment and engagement set the scope and meaning of each Learning tool prowess. Each is a complex construct, which may be derived from physical, social and cognitive theories.

Self-determination theory (SDT) is a macro-theory of human motivation concerned with the development and functioning of personality within social contexts (Ryan R. &., 2000). SDT relates enjoyment (during social activities) with intrinsic motivation. The construct of intrinsic motivation describes natural inclination toward spontaneous interest and exploration that is essential to cognitive and social development, and represents a principal source of enjoyment (Ryan R. &., 2000). The Intrinsic Motivation Inventory (IMI) is a validated multidimensional measurement instrument based on SDT (Ryan R. , 2006).

Engagement has been commonly conceptualized as a kind of mindfulness requiring cognitive effort and deep processing of new information (Salomon, 1897). This conceptualization is relevant for children's play since a dominant function of play is learning. Learning requires engaged attention. Read et al. propose that engagement could be measured by observing the occurrence of a set of behaviors including: smiles, laughing, concentration signs, excitable bouncing, positive vocalization, and that lack of engagement could be measured through behaviors including: frowns, signs of boredom (ear playing, fiddling) shrugs, and negative verbalization (Read, 2002)

Collaboration: towards play and learning

Children communicate and learn through social interaction and imitating one another. Inkpen et al. found that children exhibit a significantly higher level of engagement and activity when working alongside each other (Inkpen, 1999). Sluis et al. suggest that a collaborative environment is more likely to elicit increased intrinsic motivation(Sluis, 2004). Working together in small groups is shown to increase children's enjoyment, engagement and motivation (Inkpen, 1999), (Scott S.D., 2003). Based upon the assumption that a collaborative playing environment may facilitate better engagement and learning across all activity and interface styles, it may be suggested as a model of interaction for Tangram Bridge.

Case Study: Topobo

Topobo is a 3D constructive assembly system with kinetic memory, the ability to record and playback physical motion. By snapping together a combination of Passive (static) and Active (motorized) components, people can quickly assemble dynamic biomorphic forms like animals and skeletons with Topobo, animate those forms by pushing, pulling, and twisting them, and observe the system repeatedly play back those motions. For example, a moose can be constructed and then taught to gesture and walk by twisting its body and legs. The moose will then repeat those movements and walk repeatedly. The same way people can learn about static structures like buildings by playing with blocks, they can learn about dynamic behaviors like animal locomotion by playing with Topobo.(Raffle, 2006)

What issues arise when designing and deploying tangibles for learning in long term evaluation? Tangibles for learning - like all educational materials - must be evaluated in relation both to the student and the teacher, but most studies of tangibles for learning focus on the student as user. Here, we focus on the conception of the educator, and their use of the tangible interface in the absence of an inventor or HCI researcher.(Amanda P., 2008)

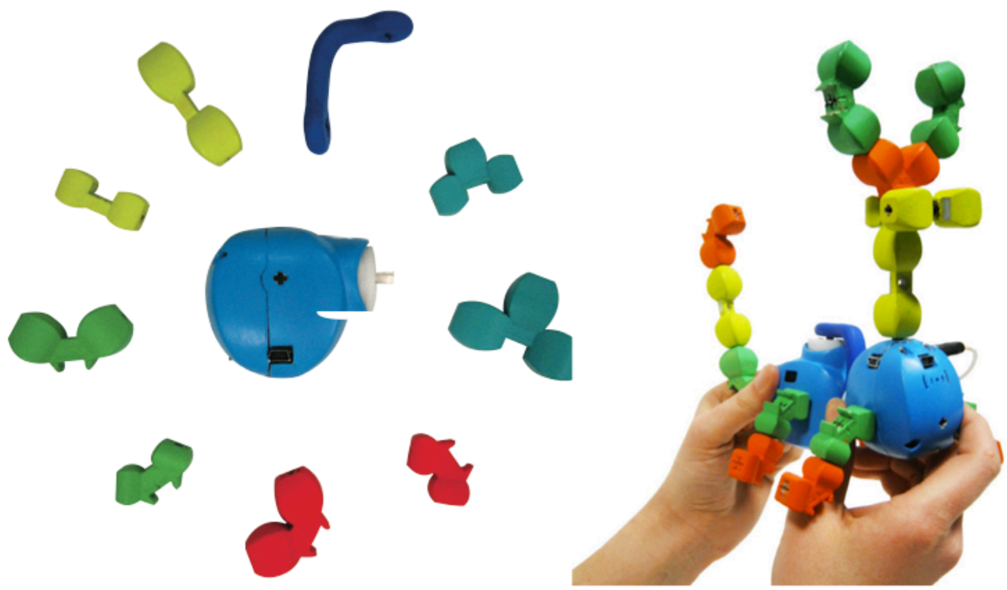


Figure 14 The Topobo system: An active surrounded by passive. Next, a Topobo 'moose' designed by 2 eight grade girls in the original Topobo evaluation (Amanda P., 2008)

Tangibles for learning (O'Malley) have sought to build on the success of educational manipulatives and constructivist learning while engaging learners in new ideas about dynamic systems through the use of hands-on experimentation with embedded computer technologies. The design principles behind Tangible User Interfaces (Ishii, 1997) include leveraging natural metaphors of object usage and taking advantage of people's inherent skills and assumptions about the physical world.

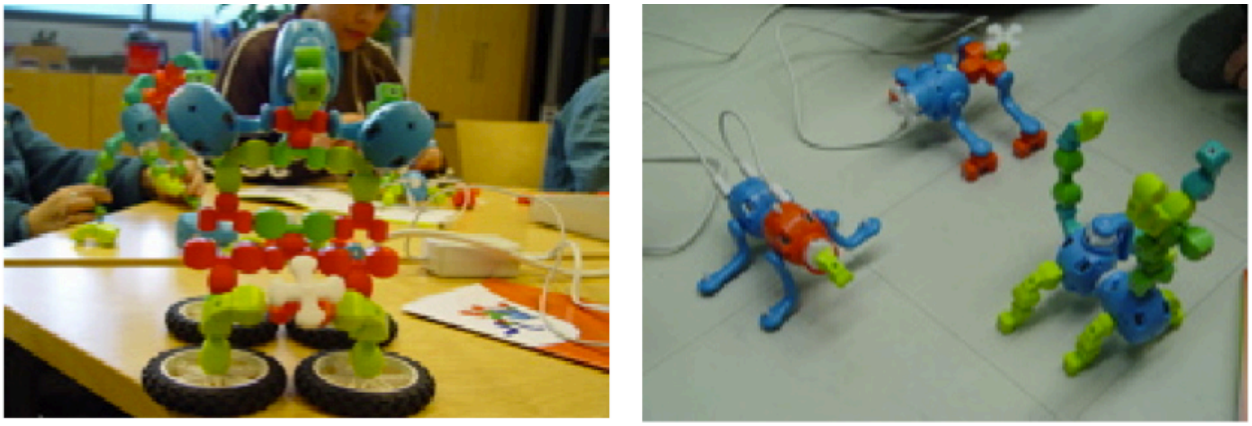


Figure 15 Creations and play by special needs children at an after-school robotics center (Amanda P., 2008)

The ability to create tools and environments that make accessible to children many of the complex and temporal processes that computers can model and demonstrate is the key.

Envisioning Topobo as a tool for simulations ranging in scale and time: it becomes an enabling technology for kinetic behavior. “In general, education is something where you want the fastest and easiest solution, and if it’s something you have to stretch your imagination to make something work for a specific situation, that’s not something people usually do in a classroom.”

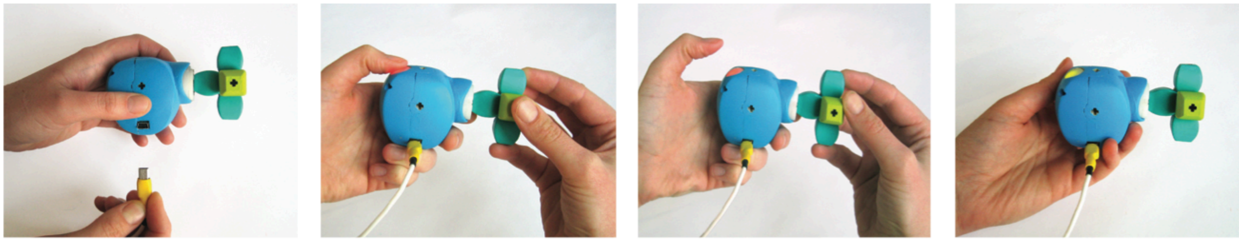


Figure 16 Basic operators used for programming Topobo creations (Amanda P., 2008)

Could Topobo succeed as a formal educational tool: could it fit within a lesson plan, state educational guidelines and other constraints that teachers juggle daily in designing their class material. (Amanda P., 2008)

Case Study: Super Tangrams

Super Tangrams is a computer-supported mathematics learning environment. The experiment covers a period of over two years of close collaboration between a university research team (Sedighian et al.), almost 50 students in grades 6 and 7 (10 to 12 year old children), and their teacher.

One of the difficult tasks teachers face is to engage children in the learning of abstract mathematical concepts. Often many children find such subjects difficult to understand and boring. Two primary reasons for this are the cognitive challenge that many mathematical subjects present and the lack of motivation on the part of children.

The Design: Super Tangrams involves the traditional Chinese Tangram puzzles in which the player is challenged to put together 7 geometric pieces to fit an outline. Once a piece is selected, the player must choose one of three transformations to move it, namely, translation, rotation, or reflection. Figure 5 depicts a puzzle in which the player has chosen to use rotation to move the square piece.

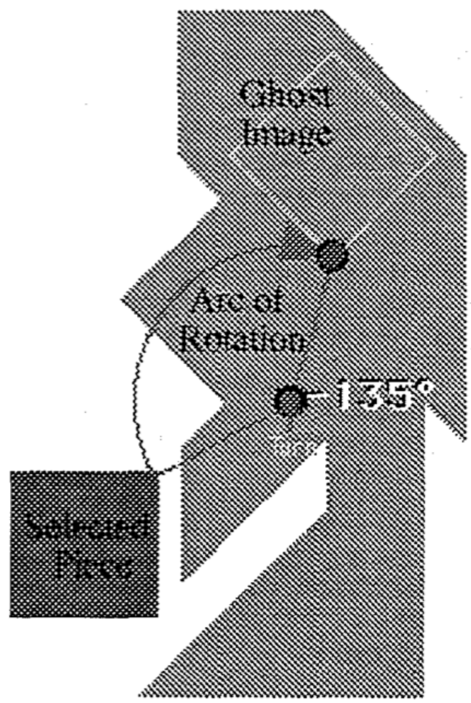


Figure 17 Image showing interaction of super Tangrams (Kamran Sedighian, 1996)

As indicated, the key elements in Figure 5 include: 1) the selected piece, 2) a formal representation of an arc of rotation with two handles (one for changing the center of rotation and the other for changing the angle of rotation), 3) a ghost image indicating the final position of the selected piece given the current settings for the angle and center of rotation. Once the player is satisfied with the current transformation settings, (s)he must click on the 'GO' button which results in an animation of the transformation of the selected piece to the location of the ghost image.(Kamran Sedighian, 1996)

General objective in designing Super Tangrams is to assist students in moving beyond their informal and intuitive understanding of 2D transformations, and to stimulate them to think about the formal mathematics involved (Sedighian, & Klawe, 1995). A few of the more specific learning goals include understanding that:

1) A rotation involves setting an angle as well as a center of rotation,

2) Rotating an object both turns it and translates it,

3) A translation arrow indicates the distance and direction in which an object will move,

4) Composite reflections are sufficient for performing all transformations, i.e., that the effect of any transformation can be achieved by an appropriate sequence of reflections.

To make the puzzles progressively challenging, create cognitive dissonance as needed, and take the player through progressive zones of learning comfort, we have built the following features into the game:

1) Some puzzles only allow the player the use of a subset of the transformations;

2) Each puzzle's pieces have a unique initial configuration;

3) Each puzzle allows the player to make a maximum number of moves;

4) Each puzzle has a score which is inversely proportional to the number of moves

5) The game has 3 levels, where higher levels provide less visual feedback thus giving more cognitive Responsibility to the player (i-e., level 1 displays the ghost image, level 2

hides the ghost image, and level 3 hides other elements of the mathematical representation).

Findings:

1. Interface design in educational software plays a crucial role in how learners interact with the educational content, and consequently how they acquire knowledge and what knowledge they acquire. The results showed significant achievement differences among students who used different interface styles. Interface techniques such as 'scaffolding' and gradual removal of visual feedback can promote reflective cognition and improve learning.

2. Direct manipulation graphical interfaces should be used with care in the context of interactive multimedia mathematics learning environments. The conventional interface design guideline calling for easier interaction and exertion of minimal cognitive load does not necessarily apply to educational environments.

3. By carefully taking into account children's cognitive and affective needs, the design can help children enjoy learning mathematics.

4. Inclusion of background music and visual aesthetics can make a learning activity more enjoyable.(Sedighian)

Case Study: TICLE: Tangible Interface to Enhance Collaborative Learning Experiences

TICLE (Tangible Interfaces for Collaborative Learning Environments) is a project that explores new ways that a computer can enhance learning without dominating the educational experience.(Lori L. Scarlatos S. S., 2001)

A system that "watches" students as they play with a Tangram puzzle on a physical tabletop, and offers help at appropriate times. Thus instead of making the computer a central part of the educational experience, our system acts as a "guide on the side" that students may either turn to for occasional help or ignore completely.(Lori L. Scarlatos Y. D., 1999)

TICLE embodies a different notion of support for collaborative learning, combining the advantages of physical learning activities with those of computer tutors. With TICLE, children are given a set of physical puzzle pieces and a specific goal designed to teach some math or science concept. A computer system observes the children as they work with the puzzle, encouraging them as they make progress and offering to give them "hints" when they don't. The hints encourage thinking about the problem by asking children to consider-smaller related problems. TICLE is unique in that it:

1. Fosters group participation, allowing children to focus on the puzzle without worrying about how to use the interface or whose turn it is to use the mouse;

2. Allows the computer to act as "guide on the side" by providing help and information only when it is needed, without dominating the educational activity; and

3. Extends the realm of possibilities for tangible interfaces, prescribing a strategy for uniquely representing the state of a puzzle such that the system can rapidly check for solutions or partial solutions.

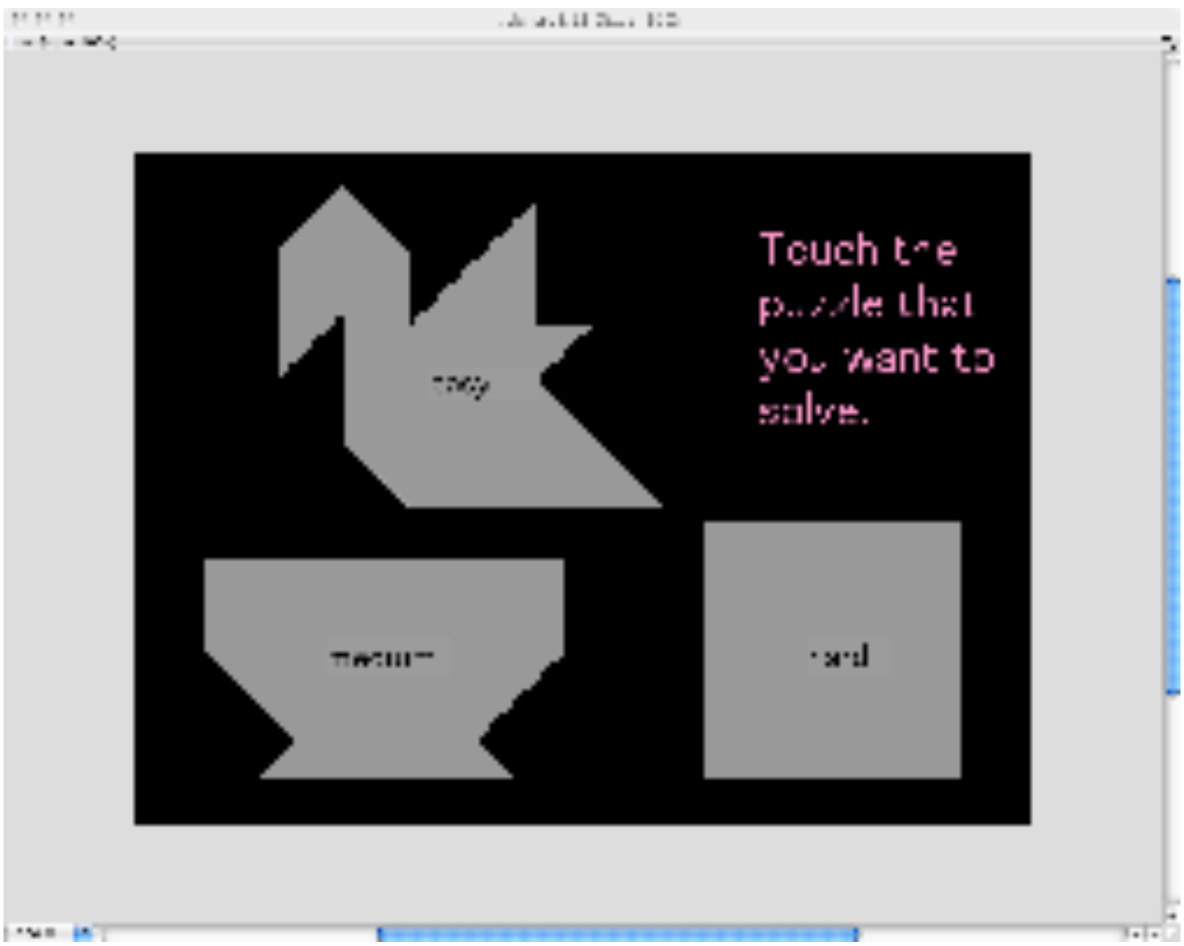


Figure 18 children experiment with a subset of the puzzle, how shapes can be contructed through compilation and re-orientation (Scarlatos)

The objective:

The system is based on the Tangram, an old Chinese geometry puzzle. The object of this puzzle is to recreate a given figure (e.g. a square) from the Tangram's seven simple shapes. The Tangram is a good choice because it can be used to show what "area" and "congruence" is without having to resort to formulas. Playing with it can also develop a geometric intuition in children, helping them to better grasp more complex geometric concepts later in their school careers.(Lori L. Scarlatos S. S., 2001)

Figure 19 children interact with TICLE Tangram prototype at the Goudreau Museum of Mathematics (Scarlatos)

The Design

Computer vision techniques helps track the puzzle pieces as they are moved about. We are extending Underkoffier's approach [5], tagging the pieces with reflective markings and tracking them with a QuickCam mounted next to a light source.

After identifying the location and orientation of the pieces, we generate an encoded string that uniquely represents the spatial relationships among the puzzle pieces. The spatial relationships and the strategy for encoding them is described in [4]. This is generated approximately once every second.(Lori L. Scarlatos Y. D., 1999)

Interpreting User Actions

Given the spatial relations among the puzzle pieces, our system then decides what the appropriate response is. Some of the conditions that it checks for are:

1. Solution has been found. The players are congratulated, and the interface offers to explain underlying geometric principles.
2. A partial solution has been found. The system encourages the players, telling them that they are on the right track.
3. Puzzle pieces are being put together the wrong way. The system gently remarks that that will not lead to a solution, and offers to give the players a hint.
4. Players hesitate for a long period of time. The system offers to either give the players a hint or review the rules and goal of the game.

5. Puzzle pieces are removed from the table, or stacked on one another. The system reminds the students that all puzzle pieces must be fiat on the table, and offers to review the rules and goal of the game.

A key factor in this system is determining the appropriate response rate. If the computer reacts to every move every second, it is likely to become annoying. If, however, it waits too long, it may become ineffective.(Lori L. Scarlatos Y. D., 1999)

A constant risk with such pre-fed set of correct operations: so as to enable step-by-step guidance is the wrong assumption that we have *all* the right answers. There may be novel ways of putting things together, or purely an iterative process where children use manipulation as an extension of cognition, to which the system maybe incorrectly responding.

Moving forward with a set of design guidelines case studies and a rough framework of requirements in terms of facilitating engaging interaction, enabling learning and providing appropriate feedback is crucial to a successful Tangible User interface.

CHAPTER 3: THEORETICAL FRAMEWORK

As illustrated through my review of literature, the premise for this project has been laid by developments in different fields. This part of the document attempts to outline my objective, assumptions, design challenge and methodology and design approach.

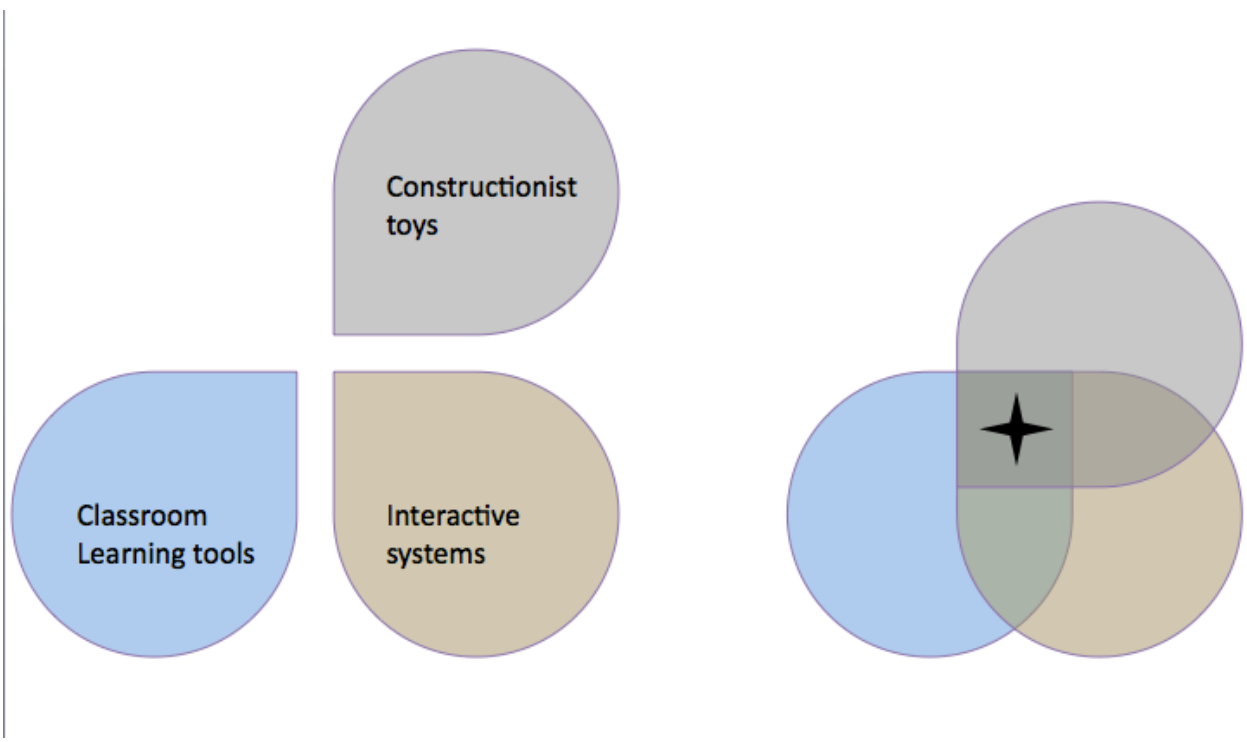


Figure 20 Identifying the intersection of three support approach for richer learning aids (Jain, 2010)

1. Children’s Education And Technology Perspective

The importance of sensory physical experience for learning has been long established by education theorists. Jean Piaget in his ‘Theory of Intellectual Development’ explains that the learning process in very young children begins by processing information coming into the brain through firsthand experiences with things, people, and feelings, depending entirely on the senses of vision, hearing, touch, smell, and taste (Paiget, 1962). The brain continually assimilates, or digests, information. Later in the development cycle, children’s brains become able to form mental pictures or symbols of things, people, and feelings. They then begin to change their existing knowledge to form new ideas. However, for several more years children continue to depend to a large degree on their senses and firsthand experiences for learning. Piaget pictured adaptation as a basically upward spiral through a series of stages and sub-stages, making possible higher and higher levels of learning (H Ginsburg, 1979), (Oren Zuckerman M. R., 2005). Traditional toys have supported this concept of educational theorists by providing physical means to learn and play, enabling children to explore abstract and tangible concepts through direct manipulation of physical objects. In recent years, with the developments in educational technology, new ways to incorporate technology into the learning experience are being explored and introduced (Marlene, 2007). This adoption has a twofold implication – it enhances the learning and development process and it makes the child more comfortable with using technology (Murphy, 2003). Most notably the ‘computer’ is hailed to be a major, positive impact on children’s social, emotional, language, and cognitive development (Shade D. , 1996)(Scoter, 2001).

The attempts to adopt technology in early childhood education, however, have not been devoid of controversy. What is to be realized is, that the full potential of technological tools will only be achieved when they are used effectively and in ways that are meaningful and appropriate to support physical abilities and critical thinking of children (Bergen, 2000). The use of the computer in its present form for the education of young children lies contrary to the ideal development process described by Piaget, who theorized that a child’s active engagement with physical objects is essential for laying the foundation for intelligence and abstract thought in the young mind.

Additionally, for very young users who can’t read or write and have still-developing motor and cognitive abilities learning and using computer interfaces is a major impediment. Preschool and even young elementary school children are still not at a literacy level required to read and understand screen/menu text and type their responses on the keyboard, nor do they have the motor skills required to operate a mouse or any standard point-and-click device (Revelle G. , 2001). Research shows that this inability is due to a variety of developmental factors - including the lack of fine motor control needed to use existing pointing devices, the lack of cognitive understanding of the mapping between controller use and what’s happening on screen, and the lack of abstract thinking skills - necessary to understand the typical screen-based representation of concepts (Char, 1990), (Revelle G. L., 1990), (Strommen, 1996)

As a result, there has been a growing interest in a new generation of interfaces that allow interaction with computers using physical objects. Of these, the most relevant ones to the topic here are computationally-enhanced physical objects or manipulative materials called "digital manipulatives"(Resnick M. E., 1998)**. A detailed discussion of the types and characteristics of these digital manipulatives is provided in the next section.**

2. Tangible Computing Research

There has been a growing body of research into approaches for linking the physical and digital worlds. Weiser's vision of ubiquitous computing (Weiser, 1991), which proposes that our computer interactions should be more tightly integrated with our real-world activities, has made a seminal impact on the research in the field. Notable areas include ubiquitous computing, augmented reality, and computer-augmented environments, which have spurred continuing research efforts throughout the 1990s.

Simultaneously, a new stream of interface research has begun to explore the relationship between physical representation and digital information, highlighting kinds of interaction that are not readily described by existing frameworks. Fitzmaurice, Ishii, and Buxton took an important step towards describing a new conceptual framework with their discussion of "graspable user interfaces" (Fitzmaurice, 1995). Building upon this foundation, Ishii and Ullmer extended these ideas and proposed the term: **Tangible User Interface**

a. Interactive surfaces

A popular paradigm for tangible interfaces is based upon the concept of "interactive surfaces," where physical objects are manipulated by users, upon an augmented surface. The presence, identity, and configuration of these objects is then electronically tracked, computationally interpreted, and graphically mediated. In the context of tangible interfaces, interactive surfaces have most frequently taken one of several major forms. Perhaps the most popular are "interactive workbenches," where objects are configured upon a near horizontal workbench. A number of tangible interfaces have also been based upon "interactive walls", having interaction based on a vertical augmented surface (Ullmer, 2002). Some good examples of interactive surfaces within our context are the commercial products of Zowie Intertainment. Zowie marketed two different playsets that used physical tokens to represent characters and artifacts. The placement and reconfiguration of these tokens within the playset was used to navigate and interact with various scenarios that were animated upon the screen (Francetic, 2000).

b. Constructive assemblies

Another major approach for tangible interfaces draws inspiration from building blocks and LEGOTM. This approach has been employed by some of the earliest tangible interfaces, often toward the ends of providing modular, electronically instrumented artifacts for constructing models of physical-world systems (Ullmer, 2002).

The concept of constructive assemblies has been used in many cases to build interactive educational toys – mostly representing an enhanced form of LEGOTM.

Notable examples for constructive assemblies include the Stackables of Kramer and Minar (Kramer K. a., 1997); the Tiles of Kramer (Kramer K. H., 1998); and Heaton's Piano (Heaton, 2000). Each of these interfaces developed additional novel features, such as the Stackables' concept of a distributed display; the Tiles' use of mobile code; and Peano's conception as a touch-sensitive, painterly medium

c. Token + constraints

Ullmer identified a new TUI approach called "tokens+constraints" (or "physically constrained tokens") (Ullmer, 2002). In this approach, physical tokens are used to describe and represent aggregates of digital information, allowing a small number of these tokens to manipulate large collections of digital information. Ullmer describes tokens as "discrete, spatially reconfigurable physical artifacts that each describe or represent an element or aggregate of digital information", and constraints as "structures that physically channel how tokens can be manipulated, often limiting their movement to a single physical dimension". Interaction methods are for such a computational system is defined by analogical mapping of physical manipulation of tokens within these constraints.

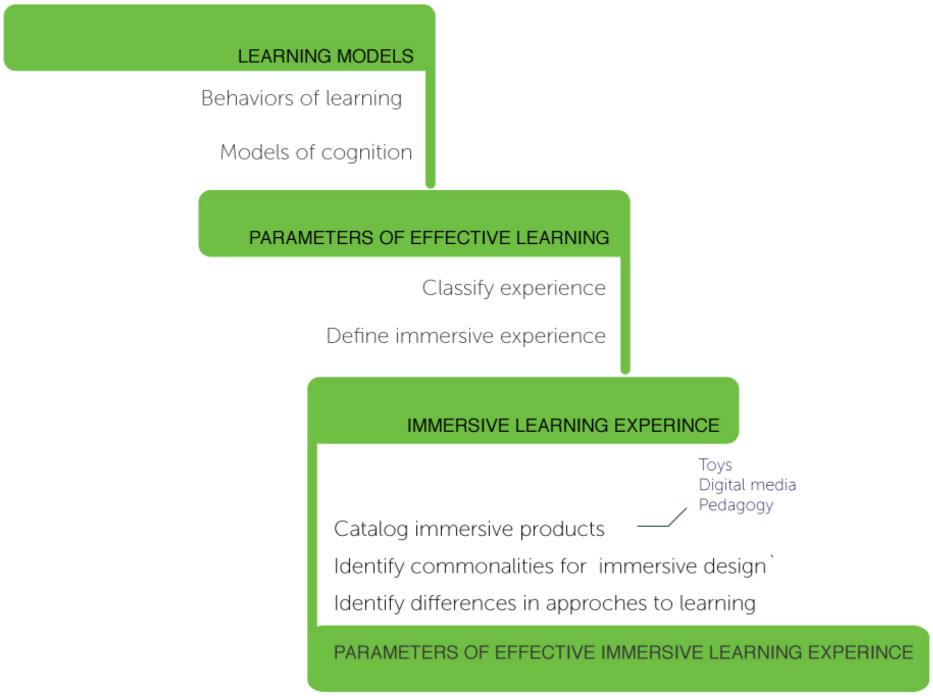


Figure 21 Structuring Theoretical Perspective (Jain, 2010)

Identifying Research Question

A few parameters that contributed to defining my final research area and specific questions were about defining the right scale of problem to solve. Theoretical framework provided enough number of opportunity spaces that would require exploratory design research. Here are some of the questions:

1. How to Enable versatility of use
2. How to pick the right scale of unit, such that there is a balance between complexity and inbuilt knowledge of the problem.

3. How to enable a unit that lends itself to multiple configurations
4. How do I pick the right scale and unit for my building blocks: rationale?

Research Question: Can Tangrams be used to teach basics of Physics?

Finally to summarize, I define the underlying premise, play principle, objective of the experiment. Through my thesis I will look at designing and experimenting with the resulting platform.

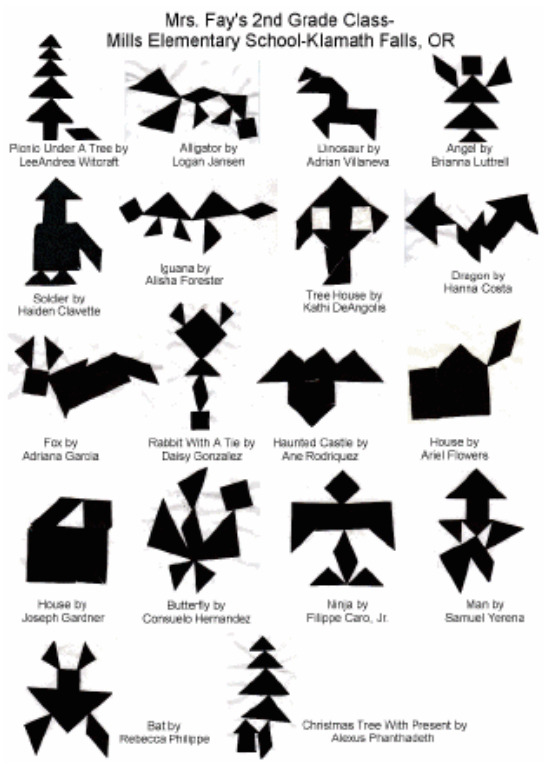


Figure 22 A panel showing work of 2nd graders with Tangrams (Keith, 1997)

Tangrams, unlike jigsaw puzzle, which must fit in a particular way to solve the problem, allow for multiple permutations to the same effect. Tangrams provide room for creativity, multiple solutions are possible to the same problem, encouraging students to think out of the box and express themselves in their creative ability to see and recognize patterns.

Premise:

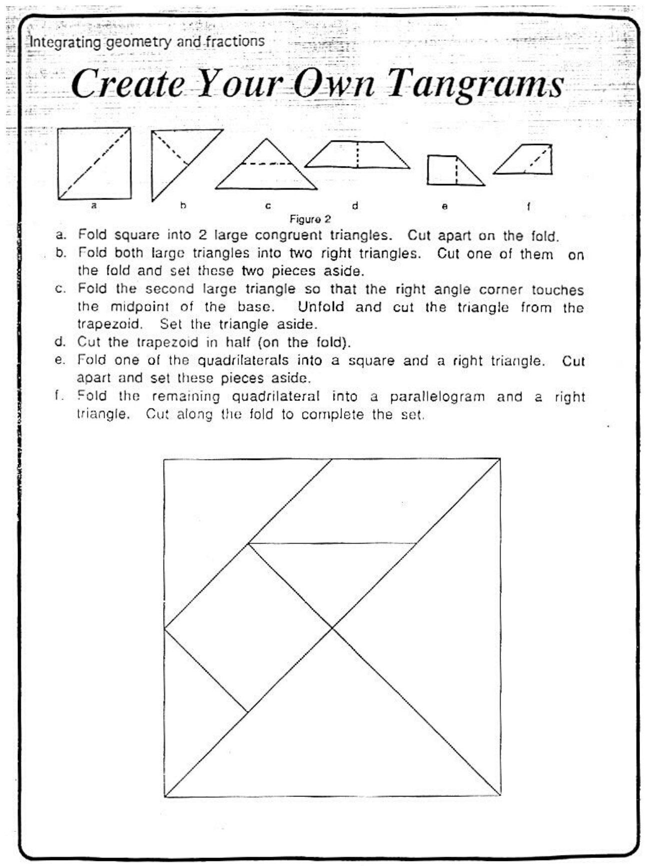
1. Premise for using Tangrams

2. Premise for application to school physics.

3. Premise for using technologically enhanced interface

4. Premise for using a Tangible user interface

Traditionally Tangrams have been used as a spatial skill based puzzle to enhance the players' visualization skills, spatial abilities and abstract thinking. For some time now, Tangrams have found popularity amongst modern schools as a teaching aid for geometry. Tangrams are based on beautifully logical geometric inter- relationships, making them ideal for the subject. Children who appreciate a more pragmatic approach to abstract problems find such tangible alternatives to problem solving very useful.



Integrating geometry and fractions

Create Your Own Tangrams

a b c d e f

Figure 2

a. Fold square into 2 large congruent triangles. Cut apart on the fold.
b. Fold both large triangles into two right triangles. Cut one of them on the fold and set these two pieces aside.
c. Fold the second large triangle so that the right angle corner touches the midpoint of the base. Unfold and cut the triangle from the trapezoid. Set the triangle aside.
d. Cut the trapezoid in half (on the fold).
e. Fold one of the quadrilaterals into a square and a right triangle. Cut apart and set these pieces aside.
f. Fold the remaining quadrilateral into a parallelogram and a right triangle. Cut along the fold to complete the set.

Figure 23 Panel showing inter-relationships of geometric shapes and their application as a math problem

Panel showing inter-relationships of geometric shapes and their application as a math problem (education)

Hypotheses: As Tangrams are purely mathematical, yet a 3dimensional entity, one seeks to explore the possibility of leveraging their spatial skill enhancing capabilities and apply them to understand basic laws of physics.

The Experiment:

We will test if Tangrams can be used as a fun way to teach children basics of physics

The experiment will be setup so as to enable children to interact easily and naturally with Tangram pieces. They will arrange these pieces and receive real time feedback from an interface.

The interface is a computer screen with a slanted surface to enable children to use it like a normal desk or easel. The children will interact with this screen using their fingers and the Tangram pieces. The interface projected on the table surface is a simple game that requires the user to make a virtual ball on the screen reach from point A to point B. When the user is able to do so, the level is completed and the user may move onto the next exercise.

The objective of the game is to use the Tangram puzzle pieces to build a “bridge” between point A and point B. Although the ball on the screen is virtual, it will behave like a real one, which is to say, gravity, (thus weight), friction, acceleration and all natural laws of physics are applied to this ball, much like a real one. If there is no bridge, the ball will fall into the “water” and sink (thus restarting the current level)

However, the game enables players to use real, three-dimensional Tangram blocks to build the bridge. The interface is able to identify each element (or pieces of the Tangram uniquely, and thus map its exact position and orientation with respect to the ball, and with respect to its neighboring pieces.

When a physically sound bridge has been built, the player presses the onscreen ball, and it begins to fall and roll, testing the players’ construction. If the player has done well, the ball will roll to point B, thus finishing the level, promoting the player to the next level.

Each section of the game tries to incorporate a new thumb of rule when it comes to laws fo physics. Levels of the game are build towards understanding principles of friction, motion on inclined plane, balance (the fulcrum and lever arm) and so on.

As the player engages in play, he or she subconsciously imbibes and form patterns about these basic thumb rules through trial and testing their designs of 'bridges'. What makes the game unique at so many levels?

1. The use of Tangrams and leverage their underlying geometry to understand physics.
2. Use of Tangrams to build bridges from point A to point B (much like a traditional Tangram outline puzzle, only without the constraint of fitting in)
3. Users interact with real world objects but manipulate a virtual environment, thus ensuring rich sensory experience with immediate response system.
4. As players have real Tangram pieces, what they build on their surface has to be a viable, real rendition of their onscreen design, thus enabling them to get a very empirical and real understanding of their design.

CHAPTER 4: METHODOLOGY

The project attempts to approach a traditional problem with the solution of a new technology. There have been few and varied antecedents, and none of them focus explicitly on tying the solution to the present classroom curriculum and environment. As such, there were many discoveries to be made along the way, and the best way to move forward was an open-ended approach to learning about the domain, by:

a) Researching into similar projects and learning from their experiences,

b) Observing the present learning environment practices at actual schools, and

c) Testing the artifact developed in real classrooms and refining it.

Learning From Others' Success

From the onset, the project aimed as much at exploring tangible technologies and artifacts as on delivering an interactive system that could be used to enhance learning activities for children. In order to avoid reinventing the wheel, an integral step of the methodology involved researching relevant projects being undertaken in places elsewhere. Identification of general and specific guidelines will help in the shaping the final proposed toy based solution

Observing Present Learning Practices

For the project to be successful, it is important to keep in mind the expectations and limitations of our target population – the children aged 7 years and up – and their present learning environment. Hence, regular visits to school and observation of the learning patterns of the young students was included as an important part of the project methodology, both in the design and the development phase.

The observations during these school visits will help in the formulation of useful insights for the design guidelines. Presently, it is the responsibility of the teacher to keep everyone on the same page, which generally implies repetition until the last student has understood the concept being taught. This slows down the whole learning process. Students should be able to learn at a pace convenient to them. Moreover, the product would emphasize learning basic physics problems through collaborative play.

These carefully designed activities will not only employ the interactive capabilities for maximum engagement, but also do so in a way that is meaningful to the child in fostering better understanding. The activities presented here are only as sample for the research prototype, loosely based on State school curriculum.

Taking The Prototype To Real-World Classrooms

After incorporating the knowledge gained from researching existing projects and observing the classrooms into a fully functional interactive prototype, the final step in the research project should involve exposing the prototype to the present classroom environment, and refining the project functionality and scope by learning in the process. In order to obtain maximum output from this step, it can be carried out in two phases:

1. Study with teachers
2. Study with children.

The two steps also represent emphasis on involving the two integral players in the classroom environment – the students and the teachers. In order to solicit important feedback, research study instruments will have to be designed that will guide the interaction with both these players. These instruments are a Focus Group study (involving teachers in a dialogue to obtain their expectations and requirements from a product like so) and a Usability study (involving students to identify usability and interaction issues with the toy).

CHAPTER 5: DESIGN AND DEVELOPMENT

Designing the Prototype:

Positioning Tangram Bridge in the world of Tangible User Interface.Tangram Bridge lies in the intersection of Tangible Manipulations and Embodied facilitation.(Eva Hornecker, 2006). Horenecer describes these Tangible Interaction spaces in great detail:

Tangible Manipulation:

Tangible Manipulation is bodily interaction with physical objects. These objects are coupled with computational resources (Ullmer, 2002), allowing the user to control computation.

Tangible Manipulation involves directly manipulating material objects that represent the objects of interest (unlike a mouse that acts as a generic and transient intermediary) (Ullmer, 2002). These objects are simultaneously interface, interaction object and interaction device (for this distinction see (M.Beaudouin-Lafon, 2000)). We termed this haptic direct manipulation. One manipulates the interaction objects, has tactile contact, feels haptic feedback and material qualities. Tangible objects can invite us to interact by appealing to our sense of touch, providing sensory pleasure and playfulness.

It's been found (Eden H., 2002) that a good representation is not sufficient for supporting discussion groups if there are no lightweight means of creation and manipulation. These provide focus, allow for creating shared visions and make these discussable. Lightweight interaction creates a 'conversational' style of interaction, giving constant feedback, allowing users to proceed in small steps, and to express and test their ideas quickly.

Directness can also refer to the relation between the manipulation of interaction devices and the acted-upon objects as well as eventual effects (M.Beaudouin-Lafon, 2000). Isomorph effects that preserve the structure of the user's manual actions by e.g. being close in time, visible nearby or of the same shape, are easily legible. If data is physically represented and manipulated, this is often provided. Yet, we feel that too many tangible interfaces aim for direct one-to-one mappings, remaining literal and missing out opportunities for employing magical metaphors or for providing the user with computational re-representations of information (S Price, 2003) and transformations of input (highlighted by the theory of distributed cognition (Hollan J. D., 2007), (Hutchins, 1995), (Kirsh D. , 1995). While aiming to exploit tangible objects' strength of providing legible relations between cause and effect, we simultaneously warn of stopping at simple, direct mappings. If tangible interaction is to become useful for complex domains and to scale up to real-world size examples, balancing legibility and computational power is one of the grand challenges. The main concepts, colloquially phrased, are:

1. **Haptic Direct Manipulation:** Can users grab, feel and move 'the important elements'?

2. **Lightweight Interaction:** Can users proceed in small, experimental steps? Is there rapid feedback during interacting?

3. **Isomorph Effects:** How easy is it to understand the relation between actions and their effects? Does the system provide powerful representations that transform the problem?

Embodied Facilitation:

With tangible interaction we literally move in physical space and metaphorically in software space. These define structure that facilitates, prohibits and hinders some actions, allowing, directing, and limiting behavior. Structure thereby shapes emerging social configurations. Tangible interaction embodies structure and thereby styles, methods and means of facilitation. We can learn from facilitation methods how to shape physical and procedural structure so as to support and subtly direct group processes. The concept of embodied constraints refers to the physical system set-up or configuration of space and objects. Embodied constraints (such as size, form, or location of objects, cf. (Scott, 2003) ease some activities and limit others, determining trajectories of action or providing implicit suggestions. The options to access and manipulate relevant objects provide access points. We can analyze systems in terms of the resources offered for observing, accessing, and interacting with the objects of interest, and in terms of privileges and restrictions. Multiple access points distribute control, keep individuals from taking over control, and lower thresholds for shy people.

Representations that are tailored for user groups can address and engage participants, offering cognitive and emotional access. While intuitiveness of interaction is helpful in the first encounter with the system, in the long run simple intuitiveness neglects users' skill (cf. (Buur, 2004) and does not scale to experienced users and complex domains. While new users should be able to quickly explore the basic syntax of interaction when manipulating objects, the semantics and refined interaction syntax may rely on domain knowledge, experience, and skill. The main concepts in this theme are:

1. **Embodied Constraints:** Does the physical set-up lead users to collaborate by subtly constraining their behavior?

2. **Multiple Access Points:** Can all users see what is going on and get their hands on the central objects of interest?

3. **Tailored Representation:** Does the representation build on users' experience? Does it connect with their skills and invite them into interaction?

Design Guidelines:

Zuckerman et al. **(Zuckerman, 2005)** suggest a set of design guideline to create better-resolved learning tools.

(1) **Generic structures vs. real-world objects** – the building blocks should enable modeling of generic, abstract structures, as opposed to real-world objects (e.g. model the generic behavior of exponential growth, rather than a specific example like a virus spreading).

(2) **Level of Abstraction** - maintain a high level of abstraction of the constructed simulations and structures, so concreteness would come from a child's analogies rather than a structure's visual form (e.g. the constructed creation should not look like something familiar from real-life).

(3) **Semantic Association** - maintains a rigorous and theoretically grounded association between the building blocks and their underlying meaning (e.g each block should represent a specific mathematical operation or concept).

(4) **Encourage analogies** - provide a method to concretize a general structure using a variety of examples (e.g. a way for children to write a meaning on each block, or a way to place pictures on a simulated structure to highlight the analogy to real-life situations).

(A) **Modularity** - develop a simple set of building blocks that can be connected in a variety of ways, enabling children to construct different models.

(B) **Multi-sensory representations** – provide multiple representations for the simulated behavior (such as light, sound, numeric display, graph) to support different styles of learning.

(C) **Coincide i/o** – manipulation and simulation occur at the same space (e.g. a child constructs and tweaks the simulation using only the blocks, with no need for an additional GUI).

(D) **Synchronous i/o** – manipulation and simulation occurs at the same time (e.g. a child can tweak a simulation and see the result in real-time).

These guidelines were referred to and instructed the design phases of Tangram bridge design and development.
Design objective: to create an engaging tool appropriate for school to use for teaching physics.

To understand the scope of application of Tangrams as a constructionist tool in classrooms, its uses were mapped across subjects that deal with abstract concepts which are difficult to grasp. The efficacy of Tangrams (or any tools) would lie in representing concepts that provide a temporal and spatial challenge; concepts, or principles that can be observed over extremely long or minute periods of time, or happen at too large or small a scale for human eye to perceive.

See next page for a map of potential application of a constructionist tool in classrooms.(Jain, 2010)

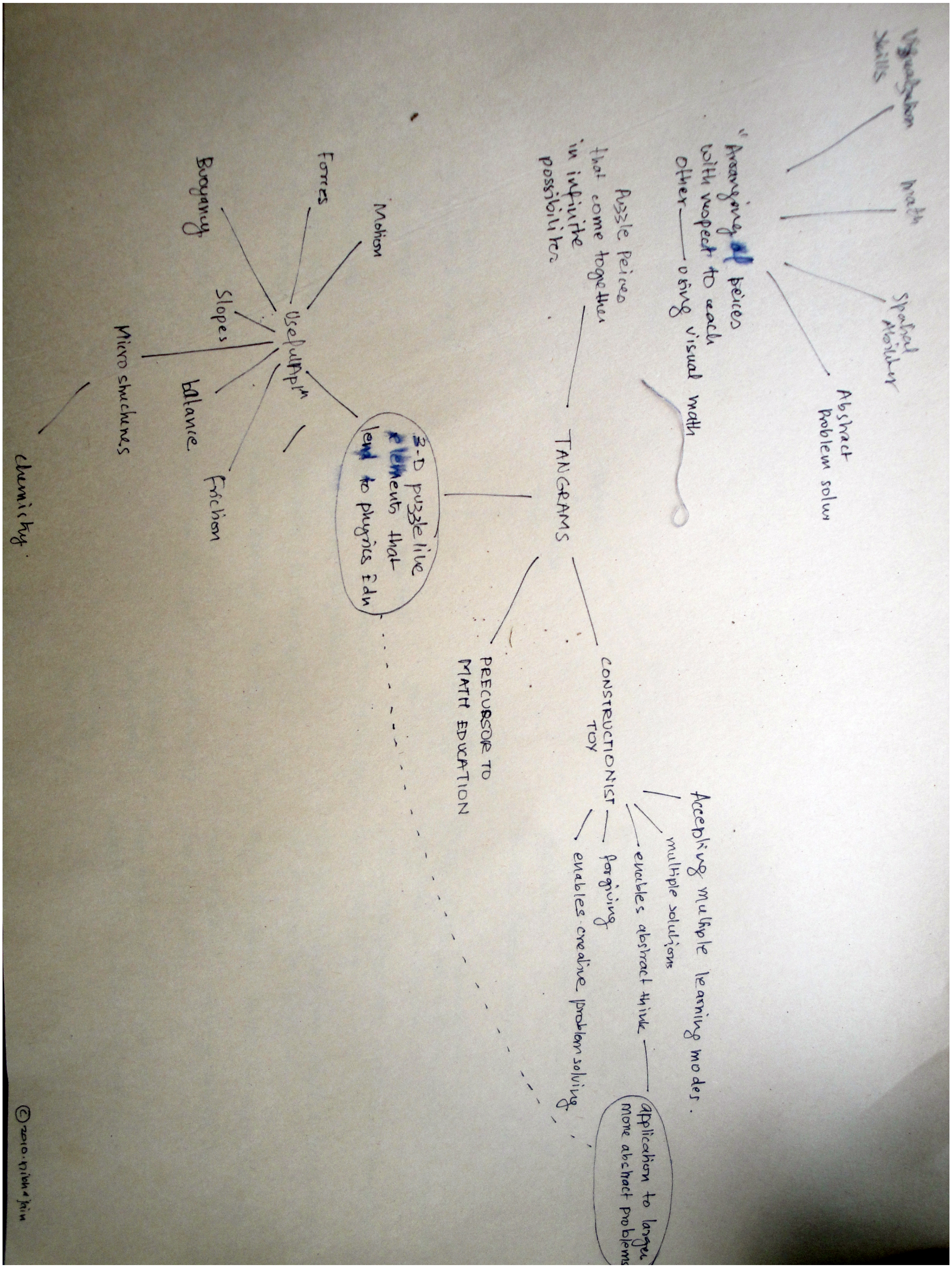


Figure 24 Map of constructionist tool application in classrooms (Jain, 2010)

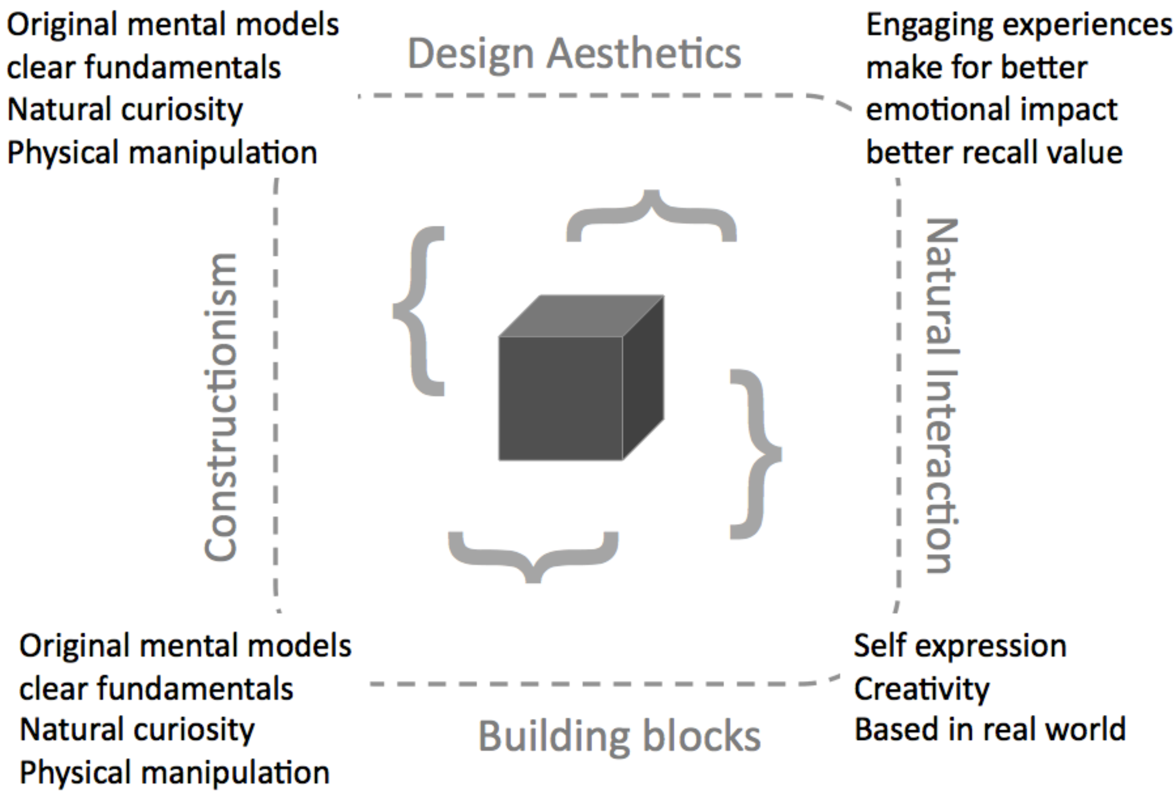


Figure 25 Defining design Ideology for Tangram bridge (Jain, 2010)

Design Ideology:

The design focuses on combining design guidelines collected through secondary literature review and apply them to the idea of creating powerful learning tools for the classroom. The Design sensibilities confirm to a simplistic design which can easily lend itself to any physical setup. The Tangram pieces developed for Tangram Bridge are translucent or neutral shades of color, proving maximum functionality and an unobtrusive visual identity that let's the virtual representations on the screen compliment the physical Tangram pieces. The setup is simple, and does not require any special equipment.

The Tangram Bridge play kit:

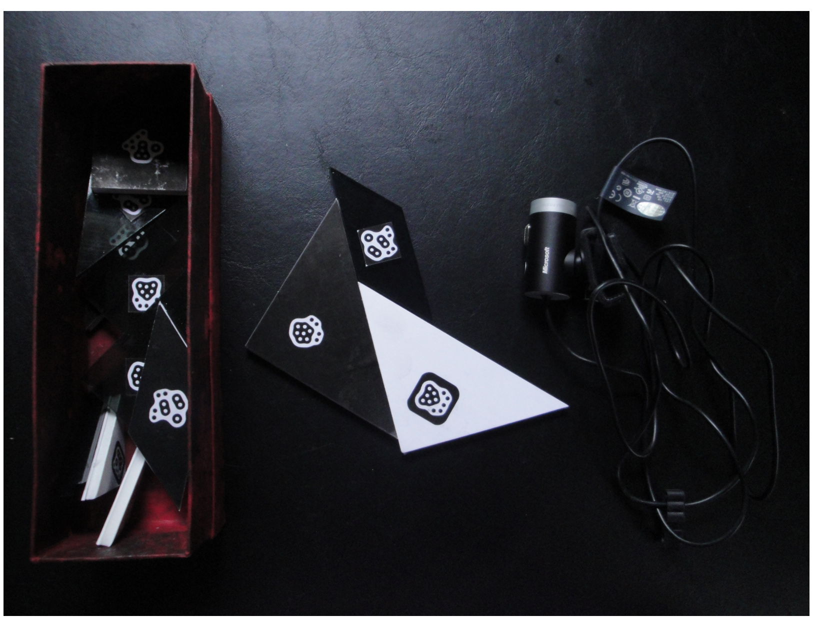


Figure 26 Tangram Bridge play kit with Tangram pieces of various materials (Jain, 2010)

Design Description:

Tangram Bridge facilitates constructive play. This is illustrated by the game and its application of same Tangram blocks to build mental models on slopes, friction, reflection, refraction and many more physics concepts. With a few tweaks to the underlying platform, the same infrastructure lends itself to many applications. Another critical principle of constructionism is reinforced by Tangrams. There is no one right way of solving problem. Tangram pieces can be arranged in myriad ways, just so long as it is physically possible to do so. There is no way a triangular block will balance itself on its tip unless supporting by another block. Children will learn this iteratively as they try to create new bridge to solve problems. The number of constraints is limited and intuitive, thus requiring no new learning. The system encourages children to try many times so reinforce learning the underlying concept, not a particular composition.

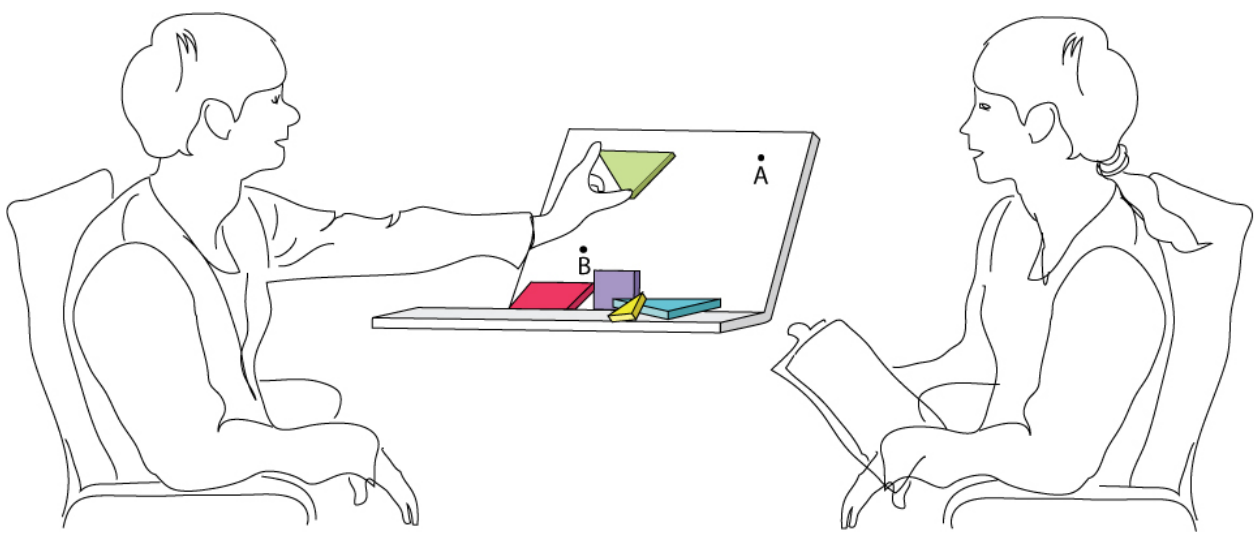


Figure 27 Panel showing projected interaction with Tangram Bridge (Jain, 2010)

Use Case Scenario:

A basic game of Tangram consists of arranging pieces to fit an outline that usually represents an abstracted animal or object. There are innumerable combinations and shapes that Tangrams lend themselves to, making it a true constructionist toy. All age groups can play with this puzzle set as its only constraint in ability to grasp abstracted shapes and resolve spatial orientation of pieces to fit that shape. Children have the innate ability to see patterns and can easily age with this toy, depending on the complexity of end composition.

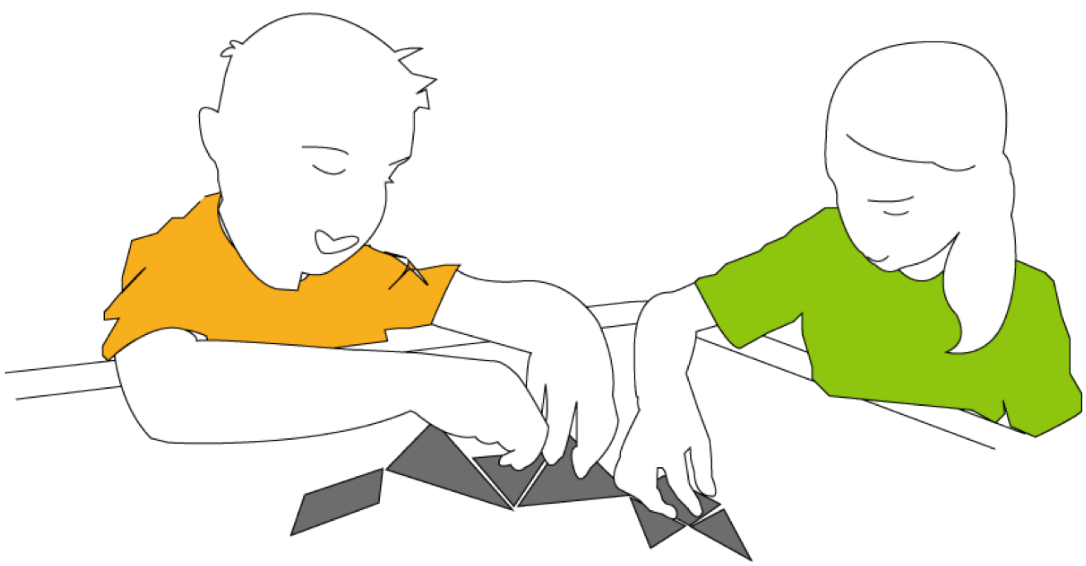


Figure 28 Traditional Tangram play scenario. children build an abstracted image of an animal. (Jain, 2010)

The Setup:

The game setup includes a) a camera to capture movement and position of b)Tangram pieces, c)a screen on which the playing canvass with the d)virtual ball shows up, e)a stand supporting the pieces onto the screen.

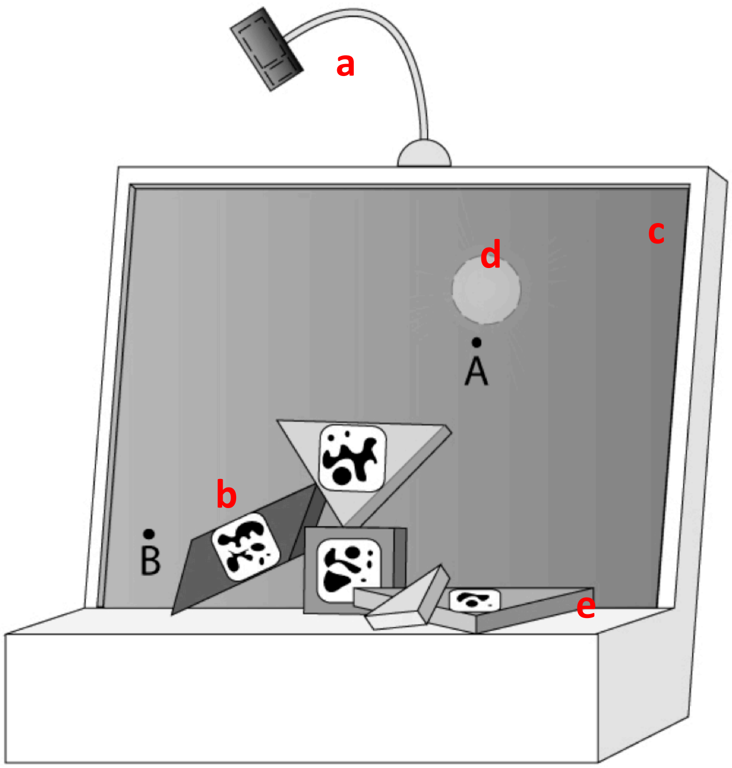


Figure 29 Proposed game setup (Jain, 2010)

The Tangram Bridge setup would be compact and minimal in infrastructure, capable of being setup in any classroom with an existing computer.

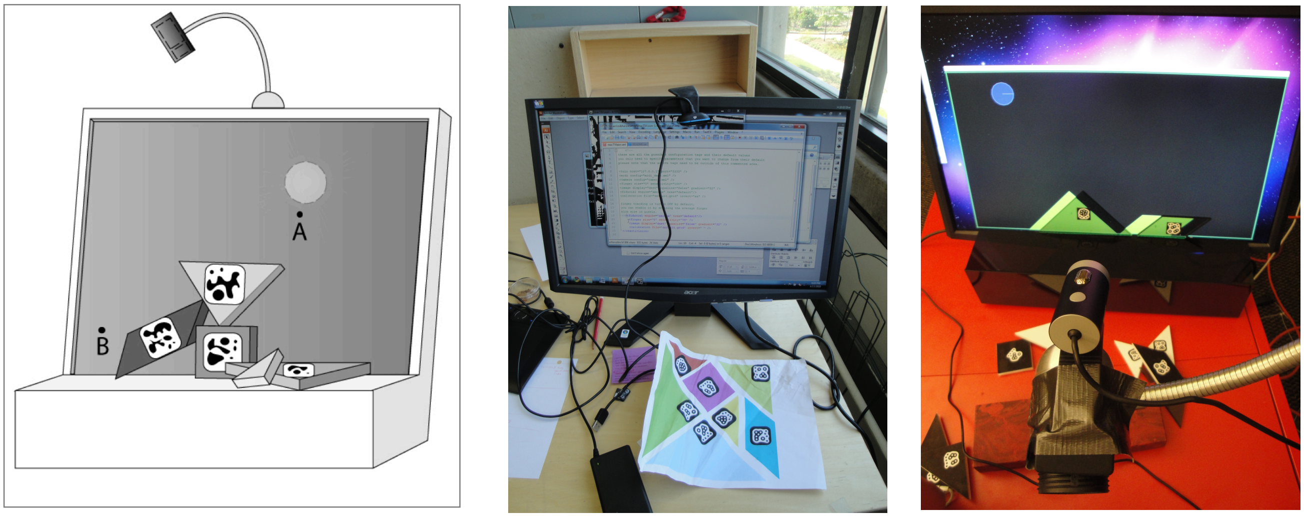


Figure 30 Panels comparing the proposed, intermediate and final Tangram Bridge setup (Jain, 2010)

Projected development of mental models:

Children naturally perceive patterns. They grasp on behaviors that repeat and start building notions of underlying principles. This supported by factual data, classroom guidance and peer collaboration can result in a rich learning experience, where the child naturally forms his mental models, as opposed to forcing himself to memorize one, borrowed from a school teacher, or a text book.

See next page for a map of opportunity spaces: (Jain, 2010)

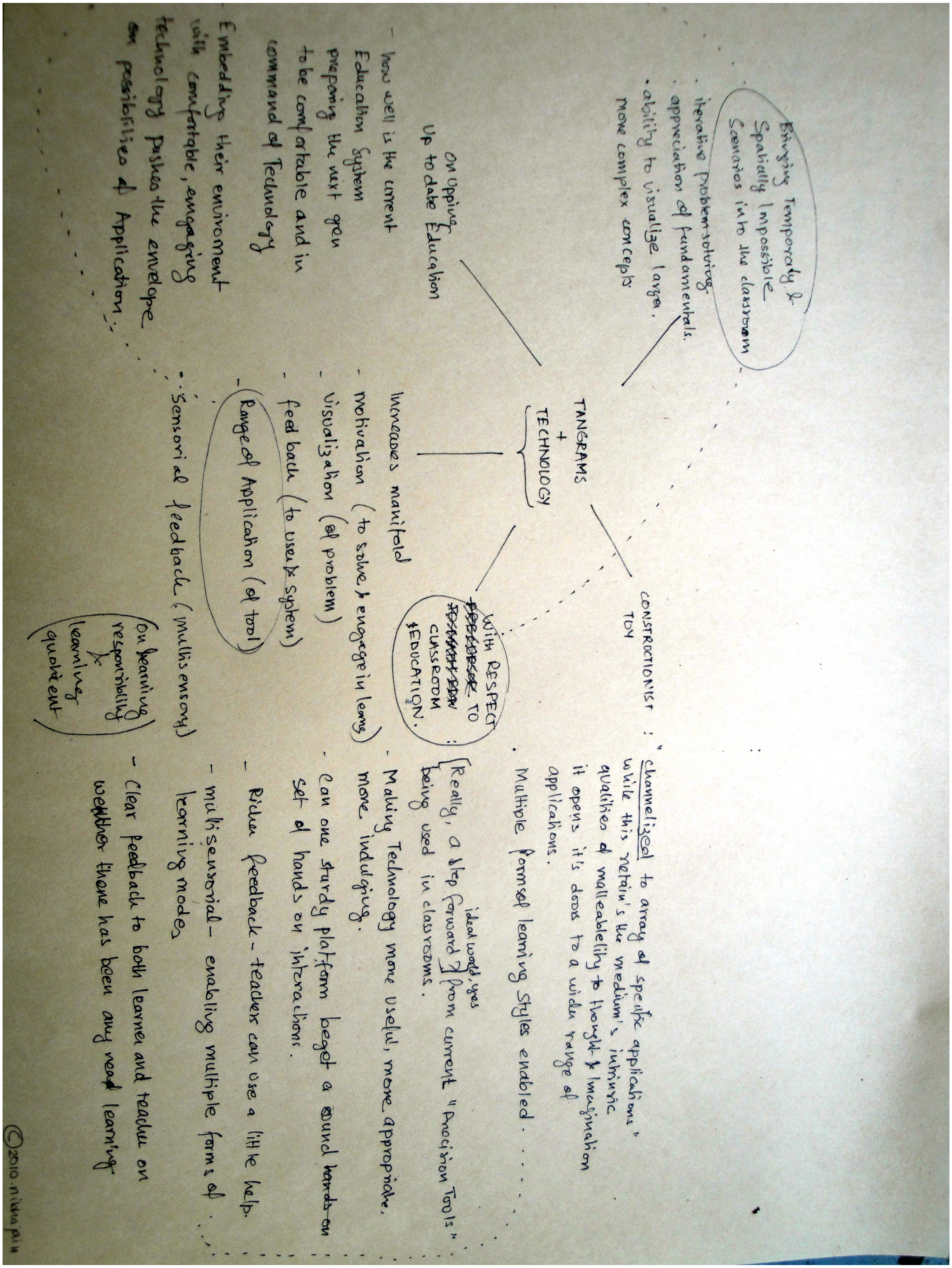
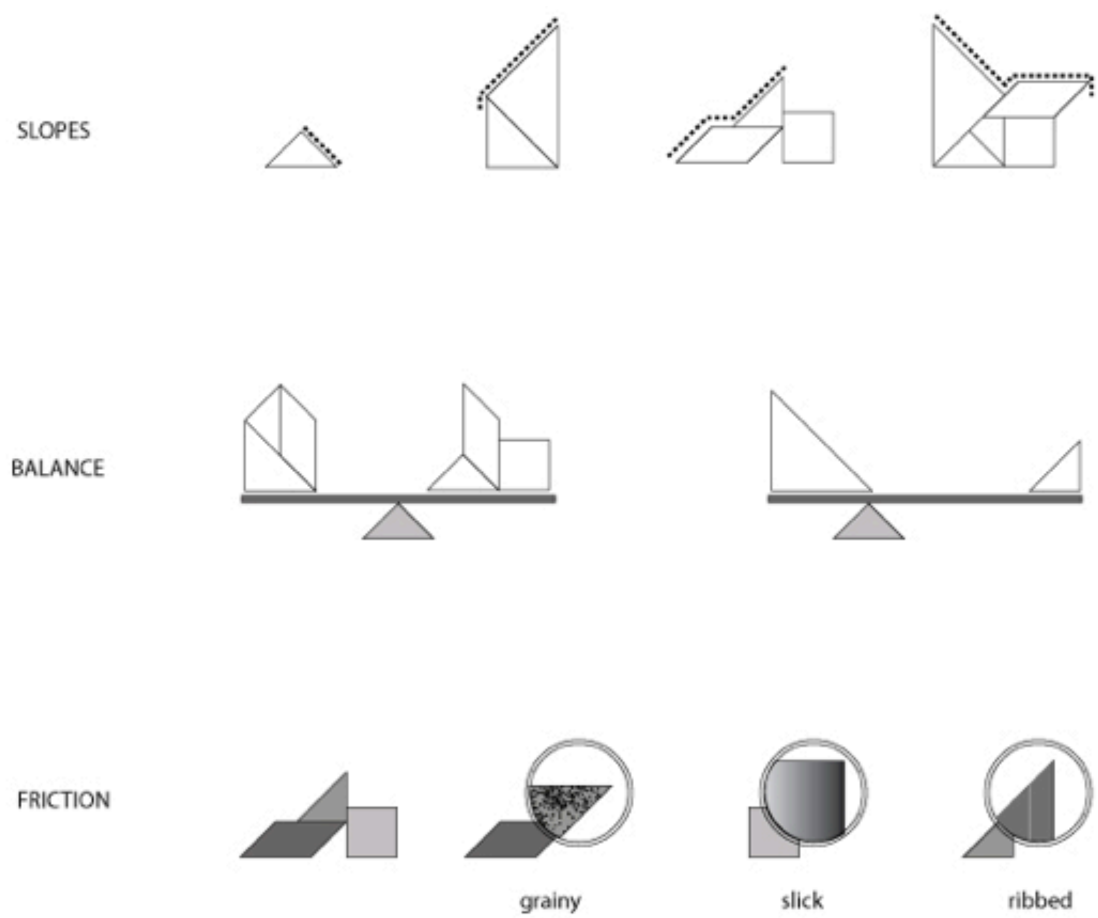


Figure 31 Design interaction opportunity map showing application of Tangram + technology in classrooms (Jain, 2010)

By interacting with Tangram Bridge, it is projected that through iterative play children will grasp principles about subjects like kinematic on slopes, role of friction in movement and concept of acceleration, vs. speed. For e.g. it is easy to notices that as you descend a sticky slide, the force of kinetic friction opposes your motion the steeper the incline, the faster an object will slide the acceleration and velocity of the box to be affected by the angle of the plane. The rate at which the object slides down the surface is dependent upon how tilted the surface is the greater the tilt of the surface, the faster the rate at which the object will slide down it.



Defining methods of explaining selected physics principles. (Jain, 2010)

Proposed Idea of levels

The environment could be explored with a multitude of settings: both real and virtual. Tangram blocks could be provided with skins: different materials produce different interaction. A separate set of wool covered Tangrams with their unique fidicual IDs could be fed into the system to create a new level of Kinematic physics game complexity.

Combining the two sets is another possibility. Another set of highly polished 'glass' Tangram blocks provide the other spectrum of this experiment.

Creating virtual skins is another possibility. Players could assign behaviors to their Tangram play environment. The physics parameters could be set such that the entire experiment is done on 'moon' or underwater.

Each of these behaviors enrich the users understanding of how gravity mass and material affect kinematics on inclined planes.

Design requirements:

These design requirements listed below were formed during and after the review of literature and identify design opportunity spaces in current education related tools.

1. The design should be modular
2. The design should follow the basic principles of constructionism, both in its form and its interaction

3. The design should facilitate engaging play, enable children to explore and learn from experimentation and collaboration.
4. The design should be able to accommodate current classroom infrastructure with minimal or no changes
5. The design should be scalable.

For Tangram Bridge to work, the computer needs to indentify Tangram pieces correctly, mirror their manipulation actively and associate the virtual balls, movement and position relative to the position of the Tangram pieces. In order to achieve this, the system should be capable of:

1. Reliably track and process unique configurations of Tangram pieces
2. Efficiently add and delete new pieces: depending on whether is it seen or not
3. Reading objects through transitions: pieces should be represented in their true state at all time. If a piece is being rotated, its effect on the environment should be apparent.
4. Being extensible and flexible to include new application

The Materials: For this project I used an array of Acrylic, wooden and foam pieces to build by material library. My assigning them unique fiduciary markers, and changing their physical properties in the code, we are able to simulate ball rolling faster on acrylic pieces than on foam pieces. This can be extended to any material the student wishes to study, by simply putting in their real values of density, and restitution, and adding more properties to create a stronger handle on physical properties, students will be able to compare, understand and learn dynamic behaviors of different materials.

Tangram Bridge:

A simple constructionist tool that explores application of traditional Tangrams to understand some of the basic principles of physics for a middle school grader.

Basic Interaction:

Children collaboratively solve a Tangram puzzle to match an existing profile, creating their own stories as the interface leads them through a series of puzzles. Children naturally create shapes using Tangram's and are very hands on with manipulating pieces to create new designs. Tangram Bridge proposes to leverage this natural engagement to facilitate learning of physics basics through Tangrams.

The project started with a very ideal concept of how the idea would come together to create an engaging, rewarding and simplistic hands on tool to initiate children into these particular physical concepts (of slopes, balance, friction, etc)

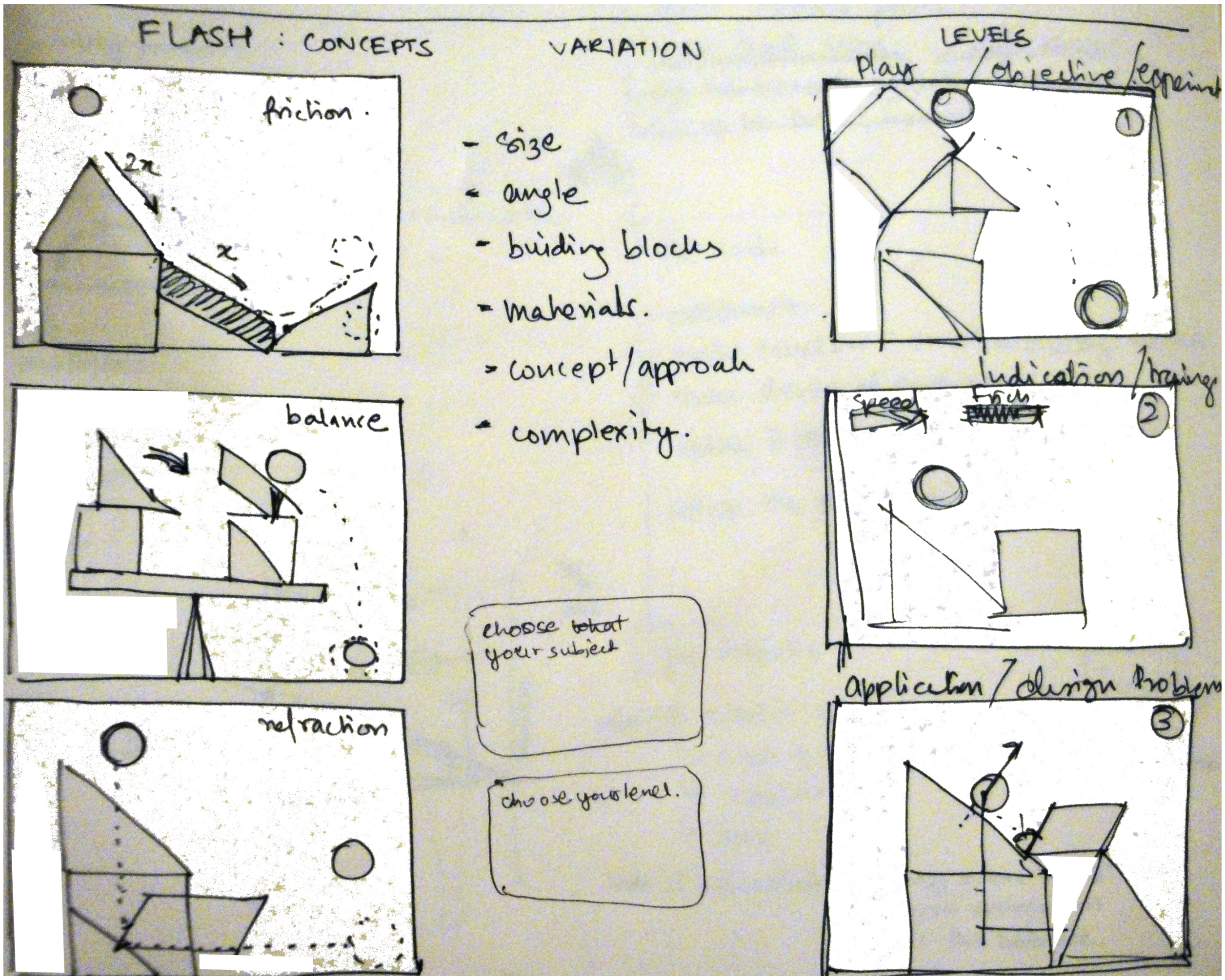


Figure 32 Initial ideas on interaction models (Jain, 2010)

Players would interact with real Tangram pieces to the effect of manipulating a simulated world to understand laws of physics.

The game:

The objective of the game is to enable a virtual ball from point A to point B on the screen with the help of augmented physical Tangram pieces. Players manipulate their pieces to direct the ball towards the goal. This is achieved by building real physically sound bridges between point A and on using the surface of the screen as a canvas for the Tangram pieces.

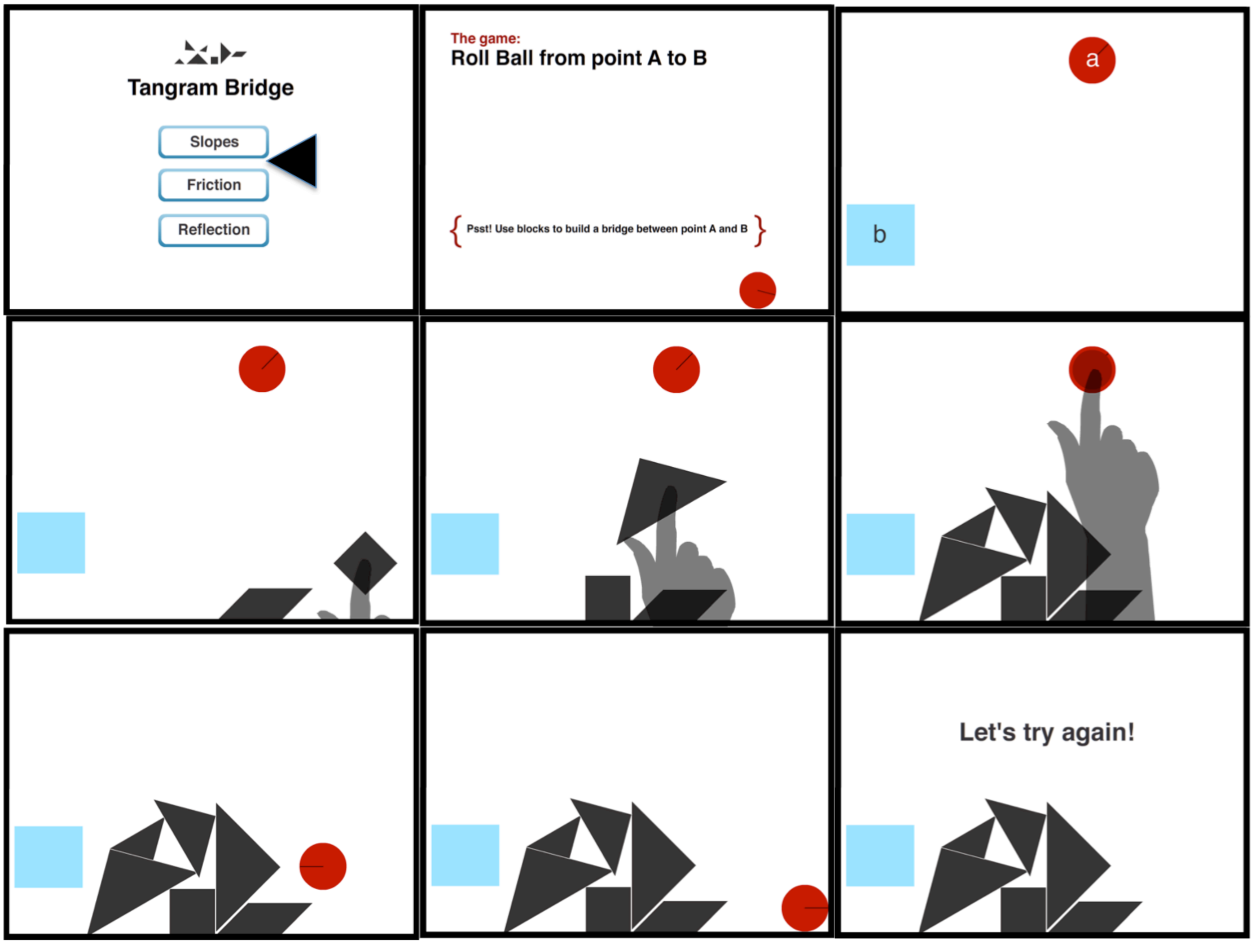


Figure 33 Panels showing Tangrams used for understanding slopes (Jain, 2010)

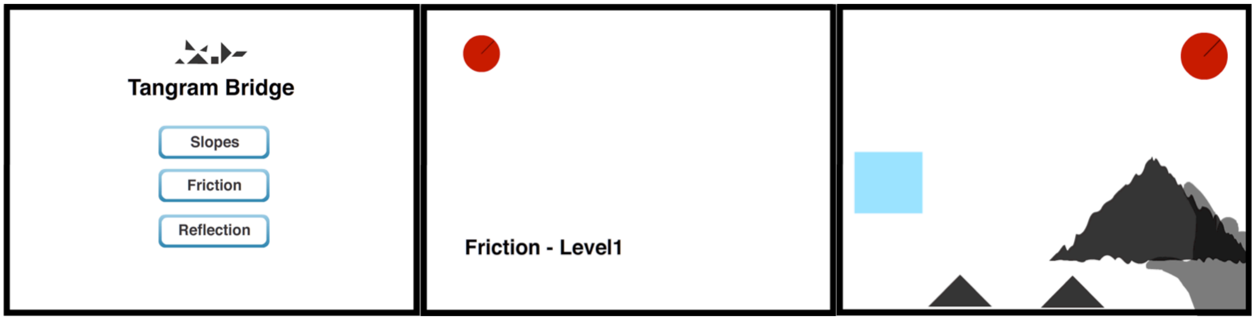


Figure 34 Panels illustrating different materials used to convey different coefficients of friction (Jain, 2010)

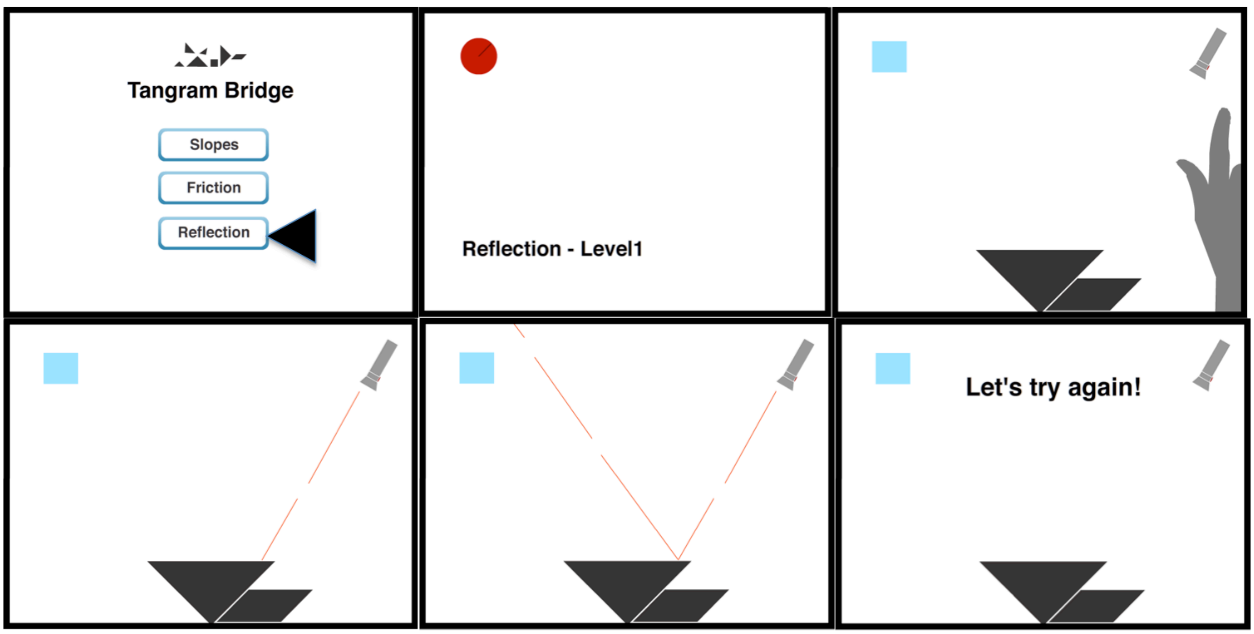


Figure 35 Panels showing use of Tangrams to understand angles of reflection (Jain, 2010)

The Infrastructure:

The Tangram pieces are marked with unique fiduciary markers enabling them with identity. This identification facilitates the program to locate their spatial co ordinates with respect to the screen and to other pieces, their rotation angle and their displacement.

reacTIVision is an open source, cross-platform computer vision framework for the fast and robust tracking of fiducial markers attached onto physical objects, as well as for multi-touch finger tracking. It was mainly designed as a toolkit for the rapid development of table-based tangible user interfaces (TUI) and multi-touch interactive surfaces. It implements the TUIO protocol, which was specially designed for transmitting the state of tangible objects and multi-touch events on a table surface.(Kaltenbrunner, 2005-2009)

reacTIVision works in tandem with fiducial markers. The application comes with a library of markers called "amoeba" (used in this project) set of 216 fiducials. These can be printed and attached to any object that needs to be tracked.

reacTIVision detects the ID, position and rotation angle of fiducial markers in the video image and transmits these values to the client application via TUIO, a protocol based on Open Sound Control.

TUIO assigns a session ID to each object in the scene and transmits this session ID along with the fiducial ID. This allows the identification and tracking of several objects with the same ID.(Kaltenbrunner, 2005-2009). This is how we enable the system to know the exact position and orientation of each Tangram piece, and the ball maps these co ordinates, creates a 'virtual contour map' and behaves with real world physics along this contour.

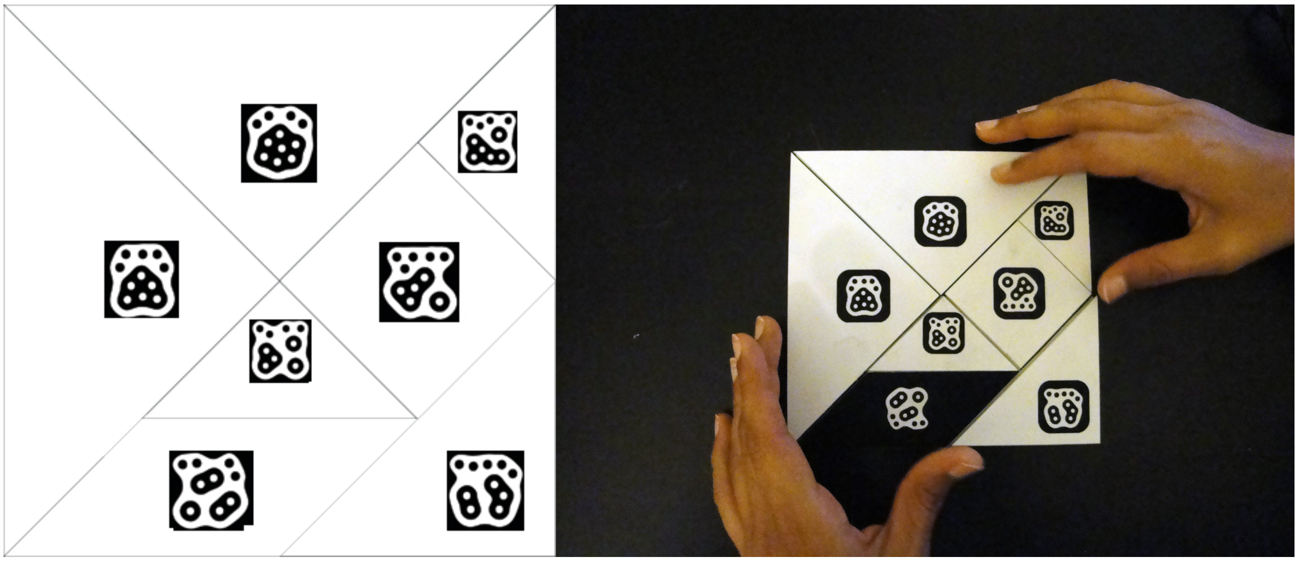


Figure 36 Each Tangram piece is marked by a unique amoeba fiducial marker (Jain, 2010)

Three things that run together to enable the game are:

1. The basic java based code, run in processing for this project
2. The physics engines plug-in enabling real life like interactions with virtual objects
3. The Reactivision setup, enabling the java program to 'see' the fiduciary markers on the Tangram pieces.

1. **The Basic Java based code**: the interaction for Tangram bridge was coded in processing language, which is a java based object oriented language. It imports libraries from java e.g. box wrap 2D (which is a translation of original Java JBox2d physics library) to simulate physics. Processing is a programming language, development environment, and online community that since 2001 has promoted software literacy within the visual arts. Initially created to serve as a software sketchbook and to teach

fundamentals of computer programming within a visual context, Processing quickly developed into a tool for creating finished professional work as well.(Reas, 2001)

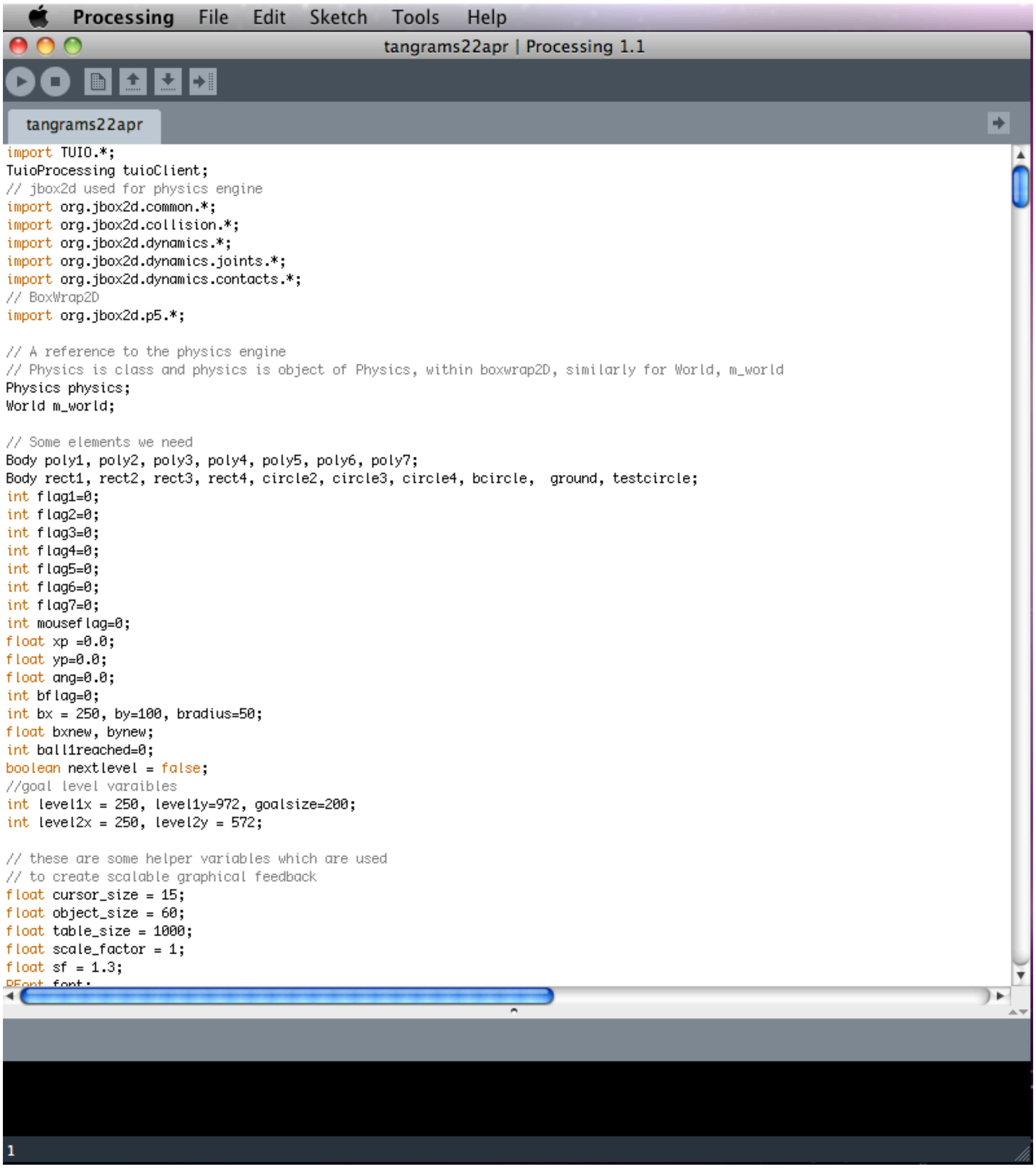


Figure 37 Screen shot of processing language code for Tangram Bridge (Jain, 2010)

Physics libraries (Box wrap 2D) assign physics behaviors to drawing and convert them into rigid objects. As this was my first time with creating any sort of code, I struggled with problems like matching physics world co ordinates with screen coordinates. At various stages of designing the interaction I ran into issues like seeing objects in a physics world, but not being able to make them fall, then eventually figuring out that they were objects without any density. To keep them from falling/ sagging initially (due to their own weight, I had to keep their initial density zero, only on mouse click do the objects acquire density, and start behaving like real world objects.

The final code emerged after a thorough set of iterations made possible by Abhishek Gupta, an ex student of Digital media department from Georgia Tech. The final code is as follows:

It starts with importing necessary libraries: TUIO to enable interaction with fiducial markers and jbox2d to enable real world physics. boxwrap 2d to talk to processing is also imported.

The processing code:

```
import TUIO.*;

TuioProcessing tuioClient;

// jbox2d used for physics engine

import org.jbox2d.common.*;

import org.jbox2d.collision.*;

import org.jbox2d.dynamics.*;

import org.jbox2d.dynamics.joints.*;
```

```
import org.jbox2d.dynamics.contacts.*;

// BoxWrap2D

import org.jbox2d.p5.*;

// A reference to the physics engine
```

Next, classes and objects within those classes are defined. Elements to represent Tangram shapes inside processing are established next.

```
// Physics is class and physics is object of Physics, within boxwrap2D, similarly for World, m_world

Physics physics;

World m_world;

// Some elements we need

Body poly1, poly2, poly3, poly4, poly5, poly6, poly7;

Body rect1, rect2, rect3, rect4, circle2, circle3, circle4, bcircle,  ground, testcircle;

int flag1=0;

int flag2=0;

int flag3=0;

int flag4=0;

int flag5=0;

int flag6=0;

int flag7=0;

int mouseflag=0;

float xp =0.0;

float yp=0.0;

float ang=0.0;

int bflag=0;

int bx = 250, by=100, bradius=50;

float bxnew, bynew;

int ball1reached=0;
```

Defining variables that will manage levels of difficulty to the game of Tangram bridge.

```
boolean nextlevel = false;
```

```
//goal level varaibles

int level1x = 250, level1y=972, goalsize=200;

int level2x = 250, level2y = 572;

// these are some helper variables which are used

// to create scalable graphical feedback

float cursor_size = 15;

float object_size = 60;

float table_size = 1000;

float scale_factor = 1;

float sf = 1.3;

PFont font;
```

Setup is run once.

```
void setup()

{

  //size(screen.width,screen.height);

  size(1440,900);

fill(0);

loop();

  frameRate(100);

  smooth();

  //noLoop();

hint(ENABLE_NATIVE_FONTS);

  font = createFont("Arial", 18);

  scale_factor = height/table_size;
```

An instance of TUIO processing client is created. This will enable processing to parse data that TUIO sends through the variables we establish. InitScene and Create objects are user defined functions.

```
tuioClient  = new TuioProcessing(this);

 // Set up everything physics

  // to use box wrap 2d, init and create object need to b be used
```

```
  InitScene();

  CreateObjects();

}
```

This is as is from the TUIO instructions.

```
// within the draw method we retrieve a Vector (List) of TuioObject and TuioCursor (polling)

// from the TuioProcessing client and then loop over both lists to draw the graphical feedback.

// draw runs in loops
```

The draw function is called to run in loops. This will enable the program to continuously talk to TUIO client, retrieve new location for where to draw and draw objects continuously.

```
void draw()

{

  background(40);

  // tangramsmoved is a funtion that checks and draws any movement in tangrams ab

  tangramsmoved();

  drawgoalboxes();


}
```

Here, virtual physics world dimensions are defined. parameters of gravity, object density and restitution (elasticity) are set to a start value. Once the game starts, these values are reset.

```
void InitScene()

{

  // Set up the engine with the sketch's dimensions

  physics = new Physics(this, width, height);

m_world = physics.getWorld();

  //ground = physics.createRect(10, height - 20,  width - 10, height - 5);

  setGravity(0.0,0.0);

  physics.setDensity(0.0);

  physics.setRestitution(0.5);
```

```
  //physics.setBullet(true);

  // methods and fucntions are the same thing sketchtangrams finction will be used to make things pretty

  //physics.setCustomRenderingMethod(this, "sketchTangrams");


}
```

This function is continuously checking if the ball has been set into motion.

```
void tangramsmoved()

{

  // for the ball

  if(bflag ==0){


setGravity(0.0,0.0);

physics.setDensity(1.0);

bcircle = physics.createCircle(bx, by, bradius);

physics.setDensity(0.0);

bflag=1;

  }
```

All this is not really used, this is as is from TUIO library, and take care of scaling objects with respect to distance of camera

```
  textFont(font,18);

  float obj_size = object_size*scale_factor;

  float cur_size = cursor_size*scale_factor;
```

This is copy pasted from TUIO , detects and stores fiducials in an array

```
  Vector tuioObjectList = tuioClient.getTuioObjects();

for (int i=0;i<tuioObjectList.size();i++) {

   TuioObject tobj = (TuioObject)tuioObjectList.elementAt(i);

   stroke(0);
```

```
   fill(150);


   xp= tobj.getScreenX(width);

   yp= tobj.getScreenY(height);

   ang = -tobj.getAngle();

   float xhs = width/2;

   float yhs = height/2;
```

This game is setup to recognize fiducial IDs 0 to 6. A wide library of fidcuai IDs are avaible, making this game scalable to a wide array of playing pieces.

```
   // float xpang = xp + xp*cos(ang);
```

//1 The first Tangram piece:

```
if(tobj.getSymbolID() == 0) {

 if (flag1 < 3 ){

      flag1=flag1+1;

    }

    if(flag1==1){

      poly1 =  physics.createPolygon(xhs-(sf*100),yhs+(sf*200),xhs+(sf*100),yhs+(sf*0),xhs-(sf*100),yhs-(sf*200));

    }

Vec2 v1 = physics.screenToWorld(xp,yp);


    poly1.setPosition(v1);

    poly1.setAngle(ang);

 fill(255,255,0,150);

    stroke(0);

    strokeWeight(1);

    pushMatrix();

    translate(xp, yp);

    rotate(-ang);
```

```
    triangle(sf*-100,sf*200,sf*100,sf*0,sf*-100,sf*-200);
    popMatrix();

  }
```

// 2 The second Tangram piece:

```
  if(tobj.getSymbolID() == 1) {
    if (flag2 < 3 ){
      flag2=flag2+1;
    }
    if(flag2==1){
      poly2 =   physics.createPolygon(xhs+(sf*200),yhs-(sf*100),xhs-(sf*200),yhs-(sf*100),xhs+(sf*0),yhs+(sf*100));
    }
Vec2 v2 = physics.screenToWorld(xp, yp);
    poly2.setPosition(v2);
    poly2.setAngle(ang);

    fill(255,255,0,150);
    stroke(0);
    strokeWeight(1);
    pushMatrix();
    translate(xp, yp);
    rotate(-ang);
    triangle(sf*200,sf*-100,sf*-200,sf*-100,sf*0,sf*100);

    popMatrix();
  }
```

// 3 The third Tangram piece:

```
  if(tobj.getSymbolID() == 2) {
```

```
    if (flag3 < 3 ){
      flag3=flag3+1;
    }
    if(flag3==1){
      poly3 =   physics.createPolygon(xhs+(sf*50),yhs+(sf*100),xhs+(sf*50),yhs-(sf*100),xhs-(sf*50),yhs+(sf*0));
    }

    Vec2 v3 = physics.screenToWorld(xp, yp);
    poly3.setPosition(v3);
    poly3.setAngle(ang);

    fill(255,255,0,150);
    stroke(0);
    strokeWeight(1);
    pushMatrix();
    translate(xp, yp);
    rotate(-ang);
    triangle(sf*50,sf*100,sf*50,sf*-100,sf*-50,sf*0);
    popMatrix();
  }
```

// 4 The fourth Tangram piece:

```
 if(tobj.getSymbolID() == 3) {
    if (flag4 < 3 ){
      flag4=flag4+1;
    }
    if(flag4==1){
      poly4 =   physics.createPolygon(xhs+(sf*50),yhs+(sf*50),xhs+(sf*50),yhs-(sf*150),xhs-(sf*150),yhs+(sf*50));
    }
 Vec2 v4 = physics.screenToWorld(xp, yp);
```

```
    poly4.setPosition(v4);

    poly4.setAngle(ang);


    fill(255,255,0,150);

    stroke(0);

    strokeWeight(1);

    pushMatrix();

    translate(xp, yp);

    rotate(-ang);

    triangle(sf*50,sf*50,sf*50,sf*-150,sf*-150,sf*50);

    popMatrix();


  }
```

// 5 the fifth Tangram piece

```
 if(tobj.getSymbolID() == 4) {

    if (flag5 < 3 ){

      flag5=flag5+1;

    }

    if(flag5==1){

      poly5 =   physics.createPolygon(xhs+(sf*100),yhs+(sf*50),xhs+(sf*0),yhs-(sf*50),xhs-(sf*100),yhs+(sf*50));

    }


    Vec2 v5 = physics.screenToWorld(xp, yp);

    poly5.setPosition(v5);

    poly5.setAngle(ang);

fill(255,255,0,150);

    stroke(0);

    strokeWeight(1);

    pushMatrix();
```

```
    translate(xp, yp);
    rotate(-ang);
    fill(255,255,0,150);
    triangle(sf*100,sf*50,sf*0,sf*-50,sf*-100,sf*50);
    popMatrix();
  }
```

// 6 The sixth Tangram piece:

```
if(tobj.getSymbolID() == 5) {
    if (flag6 < 3 ){
      flag6=flag6+1;
    }
    if(flag6==1){
      poly6 =   physics.createPolygon(xhs-
(sf*100),yhs+(sf*0),xhs+(sf*0),yhs+(sf*100),xhs+(sf*100),yhs+(sf*0),xhs+(sf*0),yhs-(sf*100));
    }


    Vec2 v6 = physics.screenToWorld(xp, yp);
    poly6.setPosition(v6);
    poly6.setAngle(ang);


    fill(255,255,0,150);
    stroke(0);
    strokeWeight(1);
    pushMatrix();
    translate(xp, yp);
    rotate(-ang);
    quad(sf*-100,sf*0,sf*0,sf*100,sf*100,sf*0,sf*0,sf*-100);
    popMatrix();
  }
```

// 7 The seventh Tangram piece:

```
  if(tobj.getSymbolID() == 6) {

   if (flag7 < 3 ){

    flag7=flag7+1;

   }

   if(flag7==1){

    poly7 =   physics.createPolygon(xhs-(sf*150),yhs+(sf*50),xhs+(sf*50),yhs+(sf*50),xhs+(sf*150),yhs-(sf*50),xhs-(sf*50),yhs-(sf*50));

   }


   Vec2 v7 = physics.screenToWorld(xp, yp);

   poly7.setPosition(v7);

   poly7.setAngle(ang);


   fill(255,255,0,150);

   stroke(0);

   strokeWeight(1);

   pushMatrix();

   translate(xp, yp);

   rotate(-ang);

   quad(sf*-150,sf*50,sf*50,sf*50,sf*150,sf*-50,sf*-50,sf*-50);

   popMatrix();

  }

 // end ----------------------------------------
```

// Now the fidicuial positions and their corresponding shapes are used to create a call back system for TUIO

```
  fill(0,0,0);

  text(""+tobj.getSymbolID(), xp, yp );

 }
```

```
 Vector tuioCursorList = tuioClient.getTuioCursors();
 for (int i=0;i<tuioCursorList.size();i++) {
  TuioCursor tcur = (TuioCursor)tuioCursorList.elementAt(i);
  Vector pointList = tcur.getPath();

  if (pointList.size()>0) {
   stroke(0,0,255);
   TuioPoint start_point = (TuioPoint)pointList.firstElement();
   ;
   for (int j=0;j<pointList.size();j++) {
    TuioPoint end_point = (TuioPoint)pointList.elementAt(j);
line(start_point.getScreenX(width),start_point.getScreenY(height),end_point.getScreenX(width),end_point.getScre
enY(height));
    start_point = end_point;
   }

   stroke(192,192,192);
   fill(192,192,192);
   ellipse( tcur.getScreenX(width), tcur.getScreenY(height),cur_size,cur_size);
   fill(0);
   text(""+ tcur.getCursorID(),  tcur.getScreenX(width)-5,  tcur.getScreenY(height)+5);
  }
 }

}
```

// The following is called every time a new Tangram piece is added or removed from the screen. these callback methods are called whenever a TUIO event occurs

```
void addTuioObject(TuioObject tobj) {
```

```
  println("add object "+tobj.getSymbolID()+" ("+tobj.getSessionID()+") "+tobj.getX()+" "+tobj.getY()+" "+ang);
}

void removeTuioObject(TuioObject tobj) {
  println("remove object "+tobj.getSymbolID()+" ("+tobj.getSessionID()+")");



  if(tobj.getSymbolID() == 0 ) {
    m_world.destroyBody(poly1);
    //physics.removeBody(poly1);

    flag1=0;
  }

  if(tobj.getSymbolID() == 1 ) {
    m_world.destroyBody(poly2);
    //physics.removeBody(poly2);
    flag2=0;
  }
  if(tobj.getSymbolID() == 2 ) {
    m_world.destroyBody(poly3);
    //physics.removeBody(poly3);
    flag3=0;
  }
  if(tobj.getSymbolID() == 3 ) {
    m_world.destroyBody(poly4);
    //physics.removeBody(poly4);
    flag4=0;
  }
```

```
  if(tobj.getSymbolID() == 4 ) {
    m_world.destroyBody(poly5);
    // physics.removeBody(poly5);
    flag5=0;
  }

  if(tobj.getSymbolID() == 5 ) {
    m_world.destroyBody(poly6);
    //physics.removeBody(poly6);
    flag6=0;
  }
  if(tobj.getSymbolID() == 6 ) {
    m_world.destroyBody(poly7);
    //physics.removeBody(poly7);
    flag7=0;
  }
}

// called when an object is moved
void updateTuioObject (TuioObject tobj) {
  println("update object "+tobj.getSymbolID()+" ("+tobj.getSessionID()+") "+tobj.getX()+" "+tobj.getY()+" "+ang
    +" "+tobj.getMotionSpeed()+" "+tobj.getRotationSpeed()+" "+tobj.getMotionAccel()+"
"+tobj.getRotationAccel());
}

// called when a cursor is added to the scene
void addTuioCursor(TuioCursor tcur) {
  println("add cursor "+tcur.getCursorID()+" ("+tcur.getSessionID()+ ") " +tcur.getX()+" "+tcur.getY());
```

```
}

// called when a cursor is moved
void updateTuioCursor (TuioCursor tcur) {
  println("update cursor "+tcur.getCursorID()+" ("+tcur.getSessionID()+ ") " +tcur.getX()+" "+tcur.getY()
    +" "+tcur.getMotionSpeed()+" "+tcur.getMotionAccel());
}

// called when a cursor is removed from the scene
void removeTuioCursor(TuioCursor tcur) {
  println("remove cursor "+tcur.getCursorID()+" ("+tcur.getSessionID()+")");
}

// called after each message bundle
// representing the end of an image frame
void refresh(TuioTime bundleTime) {
  redraw();
}

//---------------------------------------
void sketchTangrams(World w) {

  smooth();
// go through each of our body lists in the physics world
  for (Body body = physics.getWorld().getBodyList(); body != null; body = body.getNext()) {

    // Define the shape as a jbox2D shape variable
    org.jbox2d.collision.Shape shape;
```

```
    // go through each of the shapes contained in the current body
        for (shape = body.getShapeList(); shape != null; shape = shape.getNext()) {
// draw the shapes based on type
    if (shape.getType() == ShapeType.POLYGON_SHAPE) {
        PolygonShape poly = (PolygonShape) shape;

// get the number of vertex points that make up the shape
     int count = poly.getVertexCount();
     if (count == 3 || count == 4)
     {
//Polygon Appearance Parameters
      fill(46,142,201,100);
      stroke(100,100,100,255);
      strokeWeight(2);
     }
     else{
//Polygon Appearance Parameters
      fill(0);
      stroke(255);
      strokeWeight(2);
     }
//Draw the polygon
     polyDraw(body, shape);


    }
    else if (shape.getType() == ShapeType.CIRCLE_SHAPE)
{
```

//Circle Appearance Parameters in a similar way

```
      circleDraw(body, shape);
     }
   }
 }
}
void polyDraw(Body body, org.jbox2d.collision.Shape shape) {
beginShape();
PolygonShape poly = (PolygonShape) shape;
//get the number of vertex points that make up the shape
  int count = poly.getVertexCount();
```

Now, the polygons are translated in term of their vertices and converted to points. These points are then translated into their relative pixel position (x and y co ordinates.) This proved to be a challenge as identifying positions relative to the world (our canvass) is different from their position on screen in terms of pixel co ordinates.

```
  //convert the polygon into points
  Vec2[] verts = poly.getVertices();
//make a vertex for each point of the polygon and convert for pixel coordinates
  for(int i = 0; i < count; i++) {
//get the position of the vertex of the shape within the body in the world (whew!!)
    Vec2 vert = physics.worldToScreen(body.getWorldPoint(verts[i]));
    vertex(vert.x, vert.y);
  }
//connect the last point with the first point and stop
  Vec2 firstVert = physics.worldToScreen(body.getWorldPoint(verts[0]));
  vertex(firstVert.x, firstVert.y);
```

```
  endShape();
}
void circleDraw(Body body, org.jbox2d.collision.Shape shape) {
//convert the shape to a circleshape
  CircleShape circle = (CircleShape) shape;
//get position of circle within body
  Vec2 center = circle.getLocalPosition();
 //get position of body within world and convert to pixel coordinates
  Vec2 wpoint = physics.worldToScreen(body.getWorldPoint(center));
 //get the radius of the circleshape in pixel format
  float radius = physics.worldToScreen(circle.getRadius());
  if(radius <30){
    fill(255);
    stroke(0);
    strokeWeight(7);
  }
  else
  {
    fill(255);
    stroke(0);
    strokeWeight(2);
  }
  //draw the circle with radius converted to diameter
  ellipse(wpoint.x,wpoint.y,radius*2,radius*2);
}
void CreateObjects()
{
  // Middle of the world
  float hw = width / 2.0;
```

```
float hh = height / 2.0;
/*
 physics.createCircle(hw, hh, 55.0);
 physics.createCircle(hw, hh, 15.0);
 physics.createCircle(hw, hh, 20.0);
 physics.createCircle(hw, hh, 15.0);
 physics.createCircle(hw, hh, 20.0);
 physics.createCircle(hw, hh, 10.0);
 physics.createCircle(hw, hh, 20.0);
 triangle(-100,200,100,0,-100,-200);
 triangle(200,-100,-200,-100,0,100);
 triangle(50,100,50,-100,-50,0);
 triangle(50,50,50,-150,-150,50);
 triangle(100,50,0,-50,-100,50);
 quad(-100,0,0,100,100,0,0,-100);
 quad(-150,50,50,50,150,-50,-50,-50);
 */


/*
poly1 =   physics.createPolygon(0,400,200,200,0,0);
 poly2 =physics.createPolygon(400,0,0,0,200,200);
 poly3 = physics.createPolygon(400,200,400,0,300,100);
 poly4 =physics.createPolygon(400,400,400,200,200,400);
 poly5 = physics.createPolygon(300,300,200,200,100,300);

 //polygons of tangrams
 poly6 = physics.createPolygon(200,200,300,300,400,200,300,100);
 poly7 = physics.createPolygon(0,400,200,400,300,300,100,300);
```

```
  */
}
void mouseClicked()
{

  if(bflag == 1){
    bflag = bflag+1;
    setGravity(0.0,-300.0);
    physics.setDensity(1.0);
    testcircle =    physics.createCircle(bx, by-1, 1);
    physics.setDensity(0.0);
    //Vec2 vtest = new Vec2(bx, by+2);
    //bcircle.setPosition(vtest);

    //Vec2 vvel = new Vec2(0.0, -300.0); // Toward bottom
    //bcircle.setLinearVelocity(vvel);
    // bcircle.setAngularVelocity(3.0);
 }
  else
{
m_world.destroyBody(testcircle);
    m_world.destroyBody(bcircle);
    bflag=0;
  }

}
void keyPressed()
{
  // Can be used to reset the sketch, for example
```

```
  physics.destroy();
  physics = null;
  InitScene();
  CreateObjects();
  flag1=0;
  flag2=0;
  flag3=0;
  flag4=0;
  flag5=0;
  flag6=0;
  flag7=0;
  xp =0.0;
  yp=0.0;
  ang=0.0;
  bflag=0;
  bx = 250;
  by=100;
  bradius=50;
  ball1reached = 0;
}

// Set the gravity (this can change in real-time)
public void setGravity(float x, float y) {
  m_world.setGravity(new Vec2(x,y));
}

void drawgoalboxes(){
  Vec2 v = bcircle.getPosition();
  if (ball1reached == 0){
```

```
    fill(85,0,34,150);

    strokeWeight(4);

    stroke(0,0,0);

    rectMode(CENTER);

    rect(level1x, level1y,goalsize,goalsize);

    fill(0,0,0);

    text("GOAL", level1x-30, level1y );


    // text(((v.x)*10)+"  "+(-(v.y)*-10), width/2, height/2 );

    //collision detection

    if (((v.y)*-10)+height/2 + bradius > (level1y-goalsize/2) && ((v.x)*10)+width/2 + bradius > (level1x-goalsize/2)
&&   ((v.y)*-10)+height/2 + bradius < (level1y+goalsize/2) && ((v.x)*10)+width/2 + bradius < (level1x+goalsize/2)){


      ball1reached =1;

    }

}


  if (ball1reached == 1){

    fill(10,205,10);

    strokeWeight(4);

    stroke(0,0,0);

    rectMode(CENTER);

    rect(level1x, level1y,goalsize,goalsize);

    fill(255);

    text("YAY!", level1x-20, level1y);

    fill(0);

    rect(width/2, height/4,250,60);

    fill(255);

    text("Proceed to Level 2!", width/2-80, height/4+5 );

    if(mousePressed == true){
```

```
     nextlevel=true;

     ball1reached=2;

   }

 }

if (nextlevel == true){

   fill(85,0,34,150);

   strokeWeight(4);

   stroke(0,0,0);

   rectMode(CENTER);

   rect(level2x, level2y,goalsize,goalsize);

   fill(0,0,0);

   text("GOAL 2", level2x-30, level2y );
```

Establishing collision detection amongst shapes for real world interaction. This will ensure the ball bounces off polygons in a realistic manner.

```
   if (((v.y)*-10)+height/2 + bradius > (level2y-goalsize/2) && ((v.x)*10)+width/2 + bradius > (level2x-goalsize/2)
&&   ((v.y)*-10)+height/2 + bradius < (level2y+goalsize/2) && ((v.x)*10)+width/2 + bradius < (level2x+goalsize/2)){


     ball1reached =3;

   }

}


 if (ball1reached == 3){

   fill(10,205,10);

   strokeWeight(4);

   stroke(0,0,0);

   rectMode(CENTER);

   rect(level2x, level2y,goalsize,goalsize);

   fill(255);

   text("YAY!", level2x-20, level2y);
```

```
  fill(0);

  rect(width/2, height/4,250,60);

  fill(255);

  text("Congratulations!", width/2-70, height/4+5 );

  if(mousePressed == true){

    nextlevel=false;

    ball1reached=0;

  }

 }

rectMode(CORNER);

 strokeWeight(0);

}
```

The final game Interaction:

When the above code is run, the canvass is set and the following window is seen:

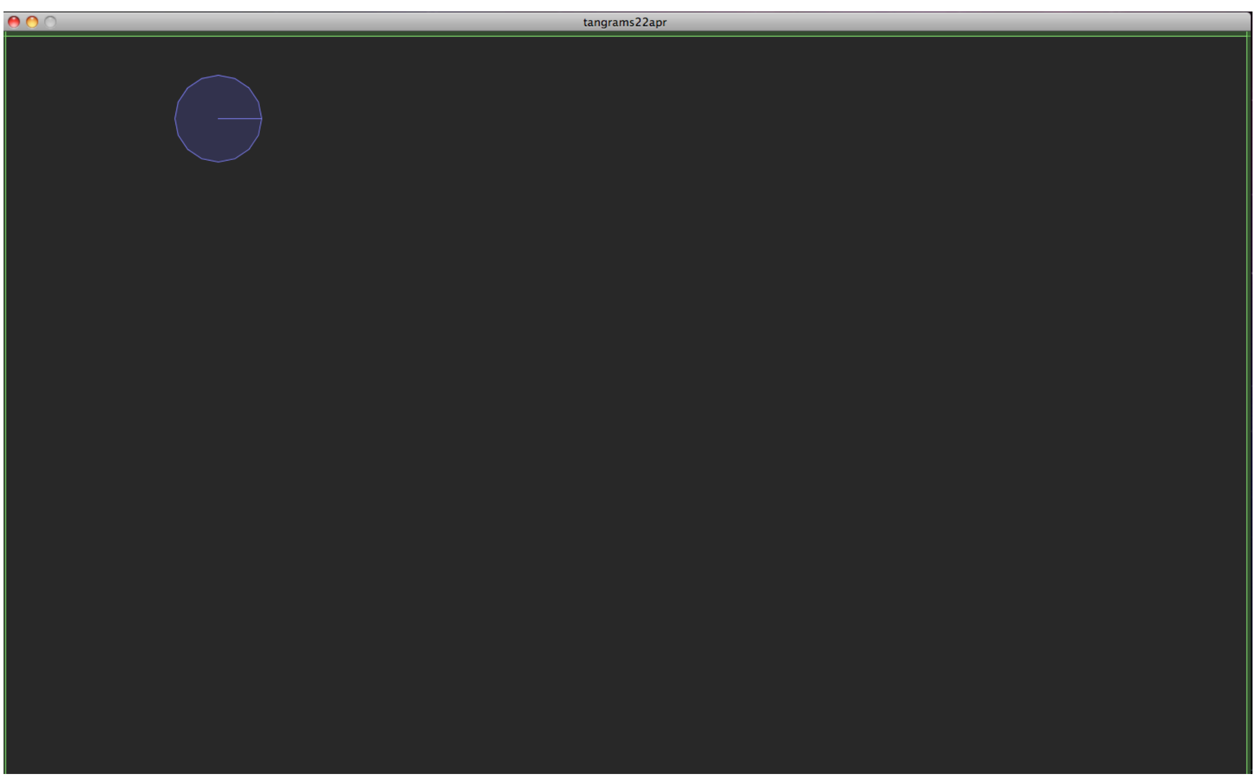


Figure 38 **Processing canvass showing the ball that will interact with the Tangram pieces.**(Jain, 2010)

At this stage, the interface is already capable of sensing fiducial markers, and if shown these shapes, represents them by drawing appropriately assigned Tangram polygons. Once the stage is set, the pieces are in position, the ball is clicked on and it starts to fall. Once it touches the Tangram pieces, it is then able to roll along their sides, follow slopes, and bounce off corners in a realistic manner.

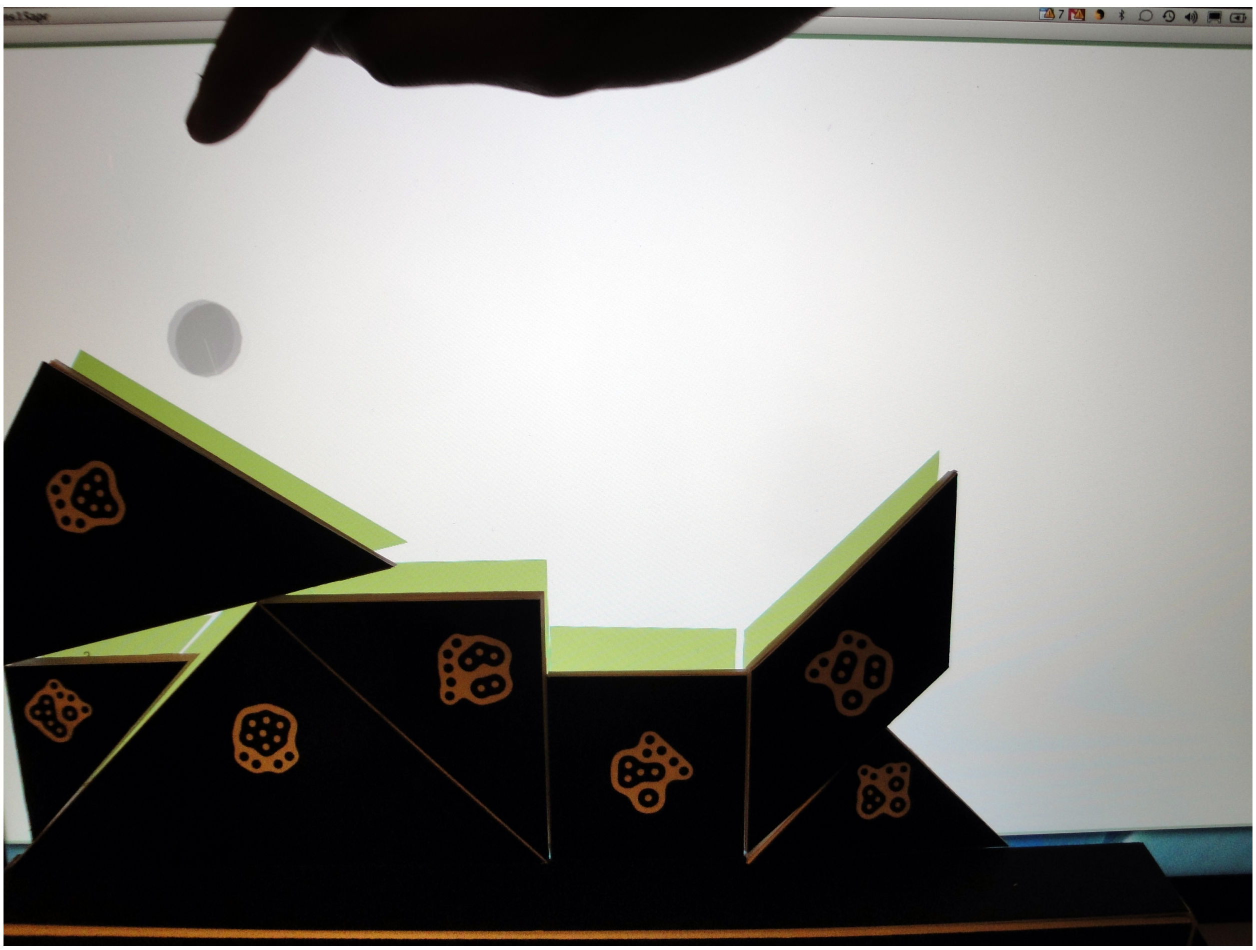


Figure 39 screenshot of game showing the ball rolling along contours of the physical Tangram pieces. (Jain, 2010)

As illustrated in the code, parameters like density, gravity and restitution are variables that can be assigned different values. This provides the possibility of making unlimited environments such as under water environments, understanding zero gravity, friction due to materials etc. All these are important yet abstract concepts that can be easily illustrated using this tool.

When the fiducials that have been assigned a shape in the code are shown tot the camera, it looks something like the following:

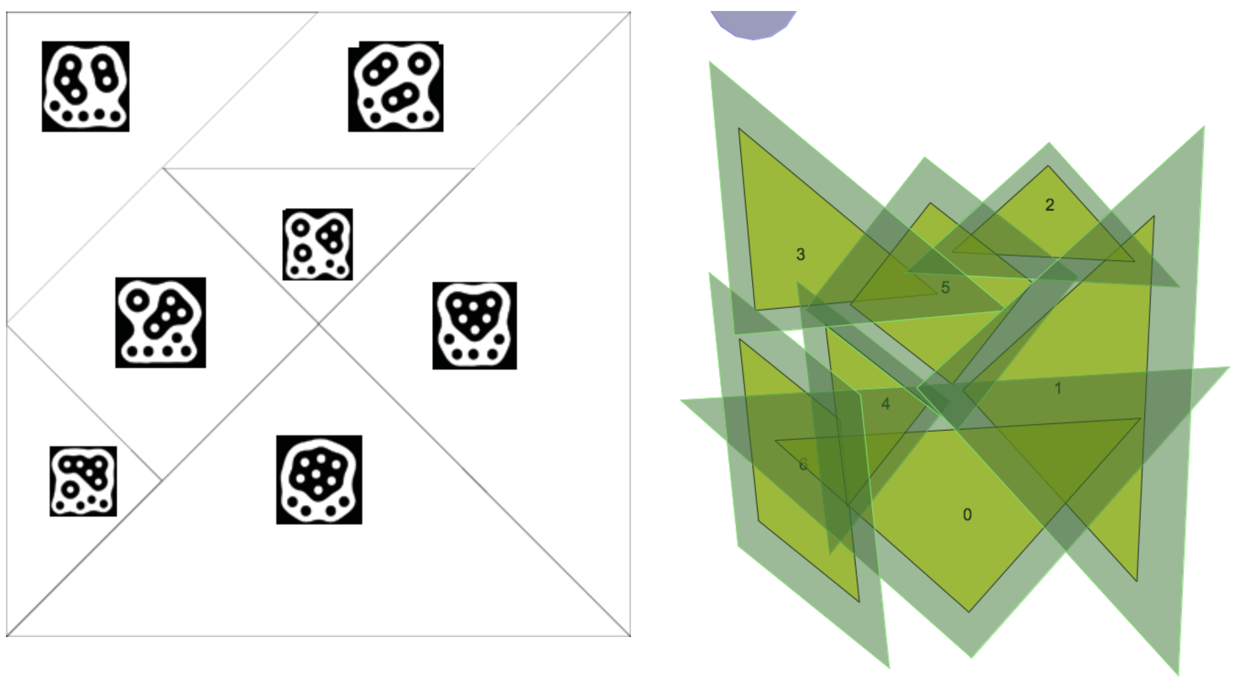


Figure 40 a representation of real and virtual pieces. The number on the virtual piece correspond the fiducial ID stuck on them.(Jain, 2010)

Game play:

The next three slides will illustrate the setup, the start and interaction of the final prototype:

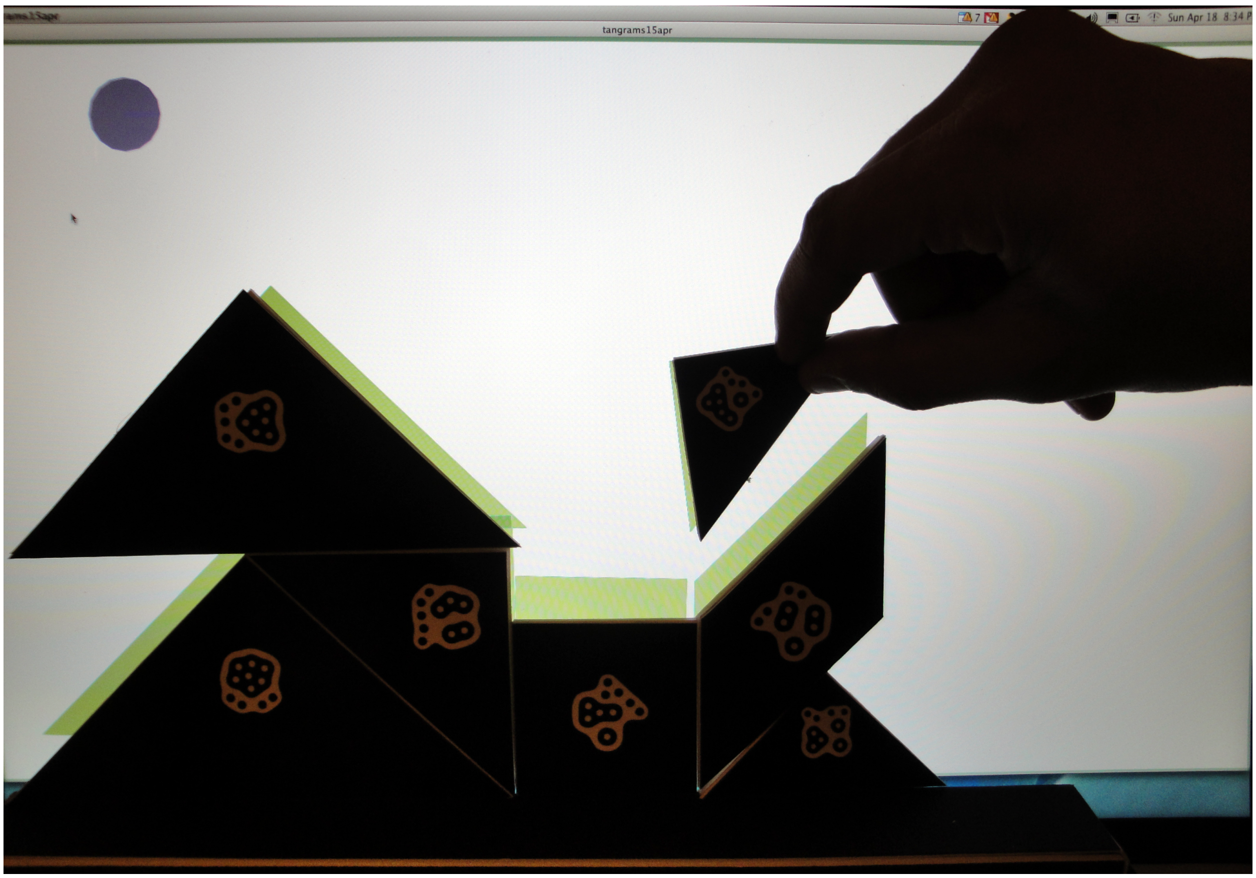


Figure 41 a user sets up the pieces to form a bridge (Jain, 2010)

The pieces are put in place. The ball will only start to roll when the user clicks on it.

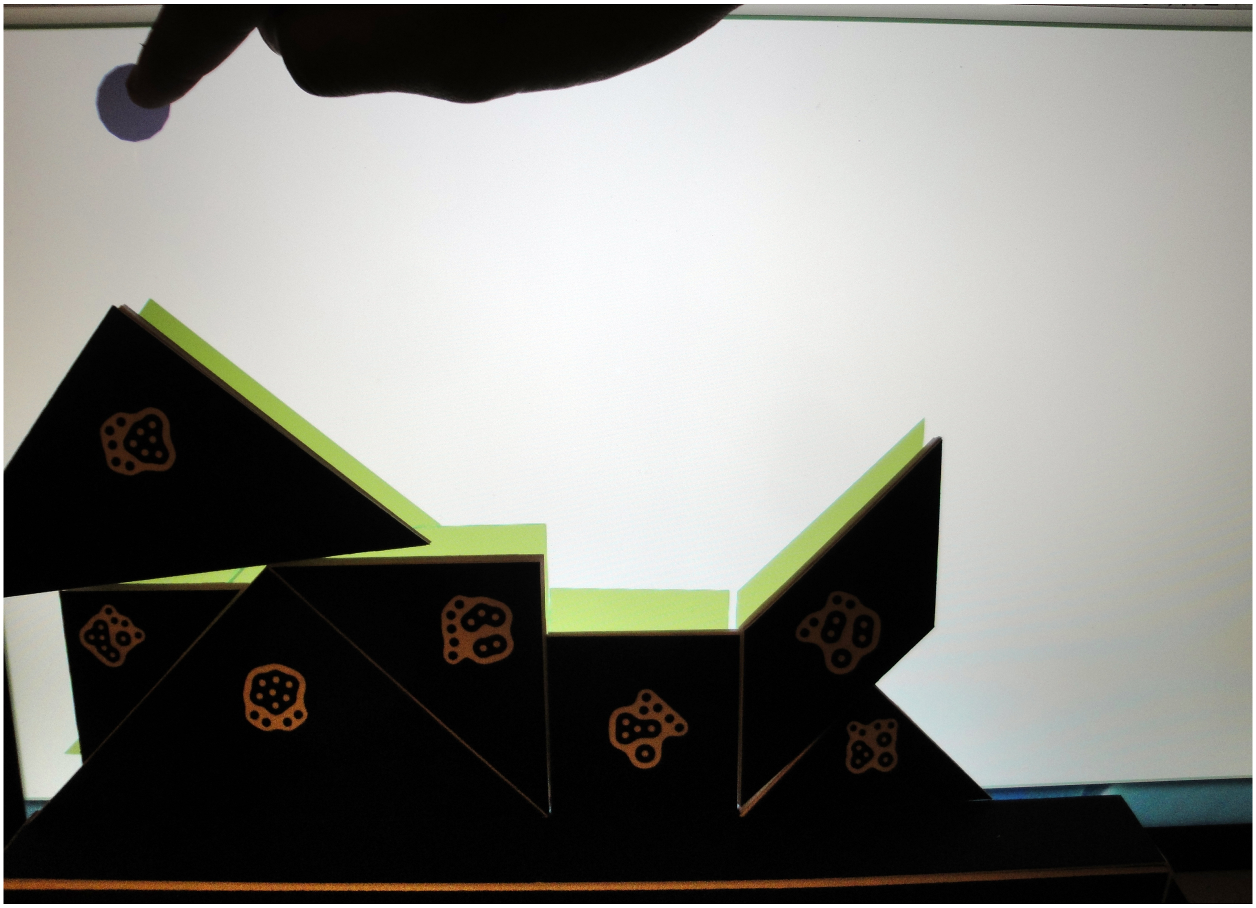


Figure 42 User clicks on the ball to initiate it (Jain, 2010)

Once the pieces are set, the user clicks on the ball to check the design of his/her bridge

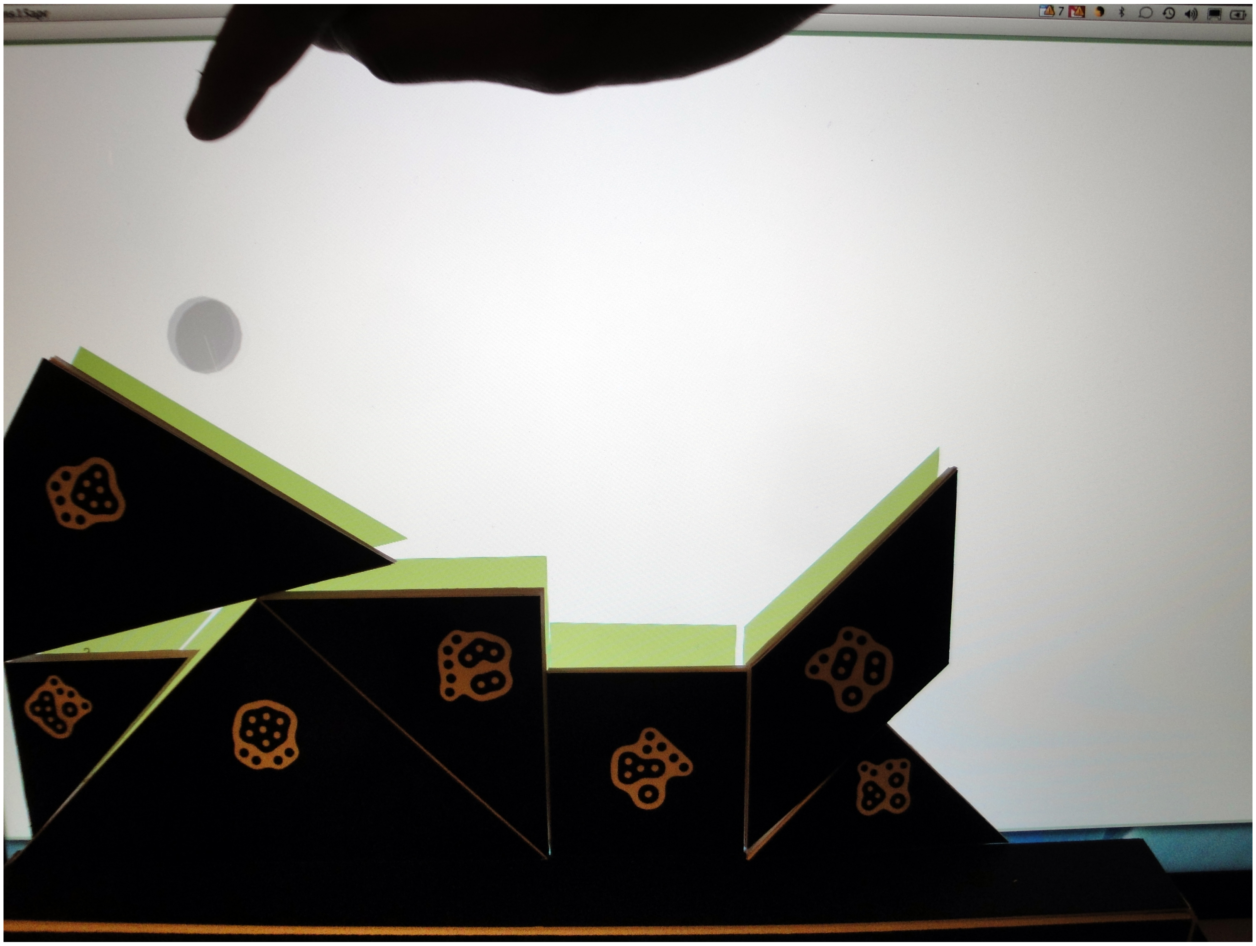


Figure 43 the ball starts to roll and reaches its destination following slopes of the pieces. (Jain, 2010)

Once the ball is released, it rolls along the contour of the physical pieces. If it reaches the goal, the user progress to next level, otherwise tweaks his/ her design to roll the ball into correct position.

CHAPTER 6: DISCUSSION AND CONCLUSION

The overall feedback this project received has been very positive. The game is engaging and users have enjoyed interacting with the Tangible user interface. It has been constantly seen as an empowering tool, lending more control over the virtual world than expected through a normal Graphical user interface. During the two occasions where users interacted with the prototype (GVU demo Day and graduate thesis presentation)

Discussions:

The following discussions emerged:

Mind mapping:

Users noted and appreciated that this product bridged the usual mental map disconnect between manipulating an object on a horizontal surface to effect changes on a vertical one (a normal screen mouse scenario). It was noted that this was especially relevant to children, who may not have strong notions of this spatial translation. The ability to manually tweak pieces and see a virtual ball roll along the contours of those very pieces present a very sound representation of a real world scenario. It does not expect children to translate what they see into abstracted forms of information, it is much more direct and forgiving.

Technology Vs. Simplicity:

I was often asked: why are you using technology when you could just use Tangram pieces and roll a real ball along the side just the same. What is the benefit? The benefit is the added motivation. Versatility of use, and scalability. It is true that simple toys are the best. That is why Tangram were picked up for the purpose of this thesis. They do not have too many constraints and the rules are embedded in the way they are shaped. They do not instruct, yet, if they are to be applied to a specific goal (such as learning physics) a setup, which is engaging, informative and motivating are critical for continued interest and interaction. Current toy trends have ensured younger generations are comfortable with technologically savvy toys. The toy looks at culminating current toy preferences with guidelines on better-engaged play.

The layer of technology is an added affordance to a preexisting game of Tangrams, or any building blocks. The technology is unobtrusive, with Each Tangram piece having a small fiduciary sticker on it. Any parameters could be assigned to these fiducial markers, making this platform a very versatile and scalable project.

Versatility:

I have used Tangram Blocks as a starting point of how constructionist toys can be given new meaning and affordance in classroom. The intent was simple. Children struggle with abstract ideas. Children naturally understand construction blocks. Children should be helped to form their own mental models. Building blocks can help understand abstract ideas better. Many experiments have been done and successfully shown that construction blocks are a successful learning tool. If the construction blocks could be given added affordances, where they are capable of changing their properties depending on class requirements (E.G: the same piece of Tangram becomes a rugged hill for teaching friction and then becomes a fat glass slab to understand refraction of light)

Tangram pieces are just a starting point; any set of constructionist toys could be induced with similar affordance to create powerful learning results.

Scalability:

The current design is capable of expanding to accommodate as many as 400 uniquely identified blocks. This can be extended to having myriad Tangram blocks in an array of materials, sizes and properties. Or could be expanded to a whole new set of shapes to introduce more variance in terms of contours, angles and tangible experience.

Application level: Tangrams are a very universal game. Children 6 years and up naturally understand how to interact with them. As shown in the proposed design, these could be applied to a vast age group of students depending on classroom requirements. For example, for really young children, understanding motion could be resolved as a purely visual exercise. The goal remains in its most simplistic form: get the ball from point A to B. for the next level of complexity, children start understanding interrelationships between slopes, acceleration, angle, friction and make informed choices on what blocks to position where in order to reach the goal. The highest level of complexity could be at he high school, even university level: where students makes numerically accurate decisions on angles, speed, slope length to arrive at the end goal. It continues to be hands on and iterative, but granularity of details changes to provide for information to the user.

Conclusion:

The initial feedback has been very positive, and it remains to be tested in a real world scenario how effective this platform would be, both in terms of application and versatility of use to teach physics.

Bibliography

Amanda P., H. R. (2008). Topobo in the Wild Longitudinal Evaluations of Educators Appropriating a Tangible Interface. *CHI 2008 Proceedings · Tangibles: Input & Output* (pp. 1129-1138). ACM press.

Antle A.N, M. D. (2009). Thinking with Hands: An Embodied Approach to the Analysis of Children's Interaction with Computational Objects. *CHI 2009.* Boston: ACM press.

Antle, A. (2007). he CTI framework: Informing the design of tangible systems for children. *TEI 2007* (pp. 195-202). ACM press.

Antle, A. n. (2009). Embodied Child Computer Interaction: Why Embodiment Matters. *Interactions archive Volume 16* .

Bakker S., A. N. (2009). Identifying Embodied Metaphors in Children's Sound-Action Mappings. *IDC 2009* (pp. 140-149). ACM press.

Barsalou, L. a.-H. (2005). Situating abstract concepts. in Pecher, D. and Zwaan, R. eds. Grounding Cognition: The Role of Perception and Action in Memory, Language, and Thought,.

Barsalou, L. N. (n.d.). The Psychology of Learning and Motivation, 43. 43-92.

Bergen, D. (2000). Linking technology and teaching practice. *Childhood Education 76 (4)* , 252–53.

Bers, M. (2008). *Blocks to Robots: Learning with Technology in the Early Childhood .*

Bongers, B. (2002). Interactivating Spaces. *Symposium on Systems Research in the Arts, Informatics and Cybernetics.*

Bruner, J. (1996). Studies in Cognitive Growth, A collaboration at the Center for Cognitive Studies.

Buur, J. (2004). Hands- only scenarios and video action walls: novel methods for tangible user interaction design. . *DIS'04* (pp. 185-192). ACM .

Char, C. (1990). Touch, click, or jump? The relative merits of different input devices for use by young children. *Annual meeting of the American Educational Research Association* .

Ciolfi, L. (2004). Situating'Place'inInteractionDesign: Enhancing the User Experience in Interactive Environments. *Ph.D. Thesis* . University of Limerick.

Diana Africano, S. B. Designing tangible interfaces for children's collaboration. *CHI '04 extended abstracts on Human factors in computing systems.* 2004: ACM press.

Djajadiningrat, T. (2002). But how, Donald, tell us how? *DIS'02* (pp. 285-291). ACM.

Dourish, P. (2001). Where the action is: the foundations of embodied interaction.

E. Hornecker, J. B. (2006). getting a grip on tangible interaction: a framework on physical space and social interaction. *CHI 2006.* ACM press.

Eden H., H. E. (2002). Multilevel Design and Role Play. *DIS'02* (pp. 387-392). ACM.

education, D. U. (n.d.). *partners for success*. Retrieved from http://www.duke.edu/web/pfs/resources/fifthmath.html

Eva Hornecker, J. B. (2006). Getting a Grip on Tangible Interaction: A Framework on Physical Space and Social Interaction. *CHI 2006 Proceedings • Designing for Tangible Interactions* , 437-446.

Fitzmaurice, G. I. (1995). Bricks: Laying the Foundations for Graspable User Interfaces. *Proceedings of CHI'95*, (pp. 442-449).

Florian Scharf, T. W. (2008). Tangicons: Algorithmic Reasoning in a Collaborative Game for Children in Kindergarten and First Class. *IDC '08* (pp. 242- 249). ACM.

Francetic, A. a. (2000). Smart Toys: Benefits of Technology-Enhanced Play. *Game Design Proceedings (now Game Developers Conference).*

H Ginsburg, S. O. (1979). Piaget's theory of intellectual development. *Prentice-Hall* .

Heaton, K. (2000). *Physical Pixels, Masters Thesis.* MIT Media Laboratory.

Heidegger, M. (1996). *Being and time.* Albany, NY: State University of New York Press.

Hollan J. D., H. E. (2007). Distributed cognition: A new foundation for human-computer interaction research. *CHI 07* (pp. 174-196). ACM.

Holmquist L. E., R. J. (1999). Token- based access to digital information. *HUC'99*, (pp. 234-245). Springer.

Hutchins, E. (1995). Cognition in the Wild,.

Inkpen, K. M.-C. (1999). This is fun! We're all best friends and we're all playing: supporting children's synchronous collaboration. *Conference on Computer Support For Collaborative Learning* (pp. 252-259). ACM press.

Ishii, H. a. (1997). Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. *CHI'97* (pp. 234-241). ACM press.

Jain, N. (2010). Exploring interactive tangrams for teaching basic physics. *Thesis* . Georgia Tech.

Jensen, M. B. (2005). Desiging the user actions in tangible interaction. *Critical Computing Aarhus* (pp. 9-18). ACM.

Kaltenbrunner, M. (2005-2009). *ReacTIVision 1.4*. Retrieved from http://reactivision.sourceforge.net/

Kamran Sedighian, M. K. (1996). Super Tangrams: A Child-Centered Approach to Designing a Computer Supported Mathematics Learning Environment. *ICLS '96: Proceedings of the 1996 international conference on Learning sciences* (pp. 490-495). ACM.

Keith, S. (1997). *creative imaginations*. Retrieved from http://www.creativeimaginations.net/kidsgallery.html

Khandelwal, M. *TEACHING TABLE a tangible mentor for pre-kindergarten math education.* Georgia Tech, Ivan Allen college, 2006.

Kirsh, D. a. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science, 18* , 513-549.

Kirsh, D. (1995). Complementary strategies: Why we use our hands when we think. *Conference of the Cognitive Science Society*, (pp. 212-217).

Kirsh, D. (1995). The intelligent use of space. . *Artificial Intelligence 73* , 31-68.

Kramer, K. a. (1997). Stackables: Manipulable Distributed Displays.

Kramer, K. H. (1998). *Moveable Objects, Mobile Code, Masters Thesis.* MIT Media Laboratory.

Lakoff, G. a. (1999). *Philosophy in the flesh: the embodied mind and its challenge to western thought.* New York: Basic Books.

Lesley Xie, A. A. (2008). Are Tangibles more fun? comparing children's enjoyment and engagement using physical, graphical and tangibel user interfaces. *TEI 08.* ACM press.

Lori L. Scarlatos, S. S. (2001). Experiments in Using Tangible Interfaces to Enhance Collaborative Learning Experiences. *CHI '01: CHI '01 extended abstracts on Human factors in computing systems* (pp. 257-258). ACM.

Lori L. Scarlatos, Y. D. (1999). TICLE: a Tangible Interface for Collaborative Learning Environments. *CHI '99: CHI '99 extended abstracts on Human factors in computing systems* (pp. 260-261). ACM press.

M.Beaudouin-Lafon. (2000). Instrumental Interaction: An Interaction Model for Designing Post-WIMP User Interfaces. *CHI 2000* (pp. 446-453). ACM.

Marina U. Bers, I. P. (2002). Teachers as Designers: Integrating Robotics in Early Childhood Education. *Information Technology in Childhood Education (2002)* , 123-145.

Marlene, S. (2007). Collective Cognitive Responsibility for the Advancement of Knowledge. *SIGGRAPH '07: SIGGRAPH 2007 educators program.* ACM.

Marshall, P. (2007). Do tangible interfaces enhance learning? *TEI 2007* (pp. 163-170). ACM press.

Marshall, P. P. (2003). Conceptualising tangibles to support learning. . *2nd International Conference on Interaction Design and Children* (pp. 101-109). ACM Press.

McNearny, T. S. (2004). from turtles to tangible programming bricks: exploration in phyisical language design.

Montessori, M. (1919). De methode Montessori: zelfopvoeding van het jonge kind. *Uitgeverij Ploegsma.*

Montessori, M. (1912). The Montessori method: scientific pedagogy as applied to child education in the "children's houses".

Murphy, K. D. (2003). eaningful Connections: Using Technology in Primary Classrooms. *National Association for the Education of Young Children – Beyond the Journal* .

O'Malley, C. a. *Literature Review in Learning with Tangible Technologies.* 2005: NESTA Futurelab Report 12.

Oren Zuckerman, M. R. (2005). Extending tangible interfaces for education: digital montessori-inspired manipulatives. *CHI '05: Proceedings of the SIGCHI conference on Human factors in computing systems.* ACM.

Oren Zuckerman, S. A. (2005). Extending tangible interfaces for education: digital montessori-inspired manipulatives. *CHI '05: Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 859-868). ACM.

Overview of Learning Styles. (n.d.). Retrieved from http://www.learning-styles-online.com/overview/

Paiget, J. (1962). Play, dreams, and imitation in childhood. *New York: Norton* .

Papert, S. (1991). *Situating constructionism.* MIT press.

papert.org.

Parreren, C. v. (1972). Sovjetpsychologen aan het woord. *Wolters-Noordhoff, Groningen* .

Raffle, H. (2006). Kinesthetic media: touch, toys & interactive materials. *SIGGRAPH '06: SIGGRAPH 2006 Educators program .* ACM.

Read, J. C. (2002). Endurability, engagement and expectations: Measuring children's fun. *he Interaction Design and Children* (pp. 189-198). Germany: Shaker Publishing.

Reas, B. F. (2001). *A short Introduction to processing*. Retrieved from http://processing.org/about/

Resnick, M. *All I Really Need to Know (About Creative Thinking) I Learned (By Studying How Children Learn) in Kindergarten*.* Cambridge, MA: MIT Media Lab.

Resnick, M. *Beyond the Centralized mindset: Starlogo and Netlogo.* MIT press.

Resnick, M. E. (1998). Digital Manipulatives: New Toys to Think With. *Proceedings of the CHI '98 Conference.*

Resnick, M. *Some Reflections on Designing Construction Kits for Kids.* MIT Media Lab + Brian Silverman Playful Invention Company.

Revelle, G. (2001). Exploration of developmentally-appropriate tangible interfaces for young children. *Internal publication* .

Revelle, G. L. (1990). The effects of practice and input device used on young children's computer control. . *Journal of Computing in Childhood Education* , 33-41.

Rieser, J. G. (1994). Imagery, Action, and Young Children's Spatial Orientation: It's Not Being There That Counts, It's What One Has in Mind. . *Child Development, 65* , 1262-1278.

Rubidge, S. a. (2004). Sensuous Geographies: a multi-user interactive/responsive installation. *Digital Creativity Vol 15, No. 4,* , 245-252.

Ryan, R. &. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55* , 68-78.

Ryan, R. (2006). *Intrinsic Motivation Inventory (IMI)*. Retrieved from http://www.psych.rochester.edu/SDT/measures/intrins.html

S Price, Y. R. (2003). Using ' Tangibles' to promote novel forms of playful learning. *Interacting with Computers 15.* ACM press.

Salomon, G. &. (1897). When teams do not function the way they ought to. *International Journal of Educational Research 13*, (pp. 89-100).

Scarlatos, L. L. (n.d.). *TICLE: Tangible Interfaces for Collaborative Learning Environments*. Retrieved from http://ms.cc.sunysb.edu/~lscarlatos/TICLE/ticle.html

Scoter, J. E. (2001). Technology in early childhood education: Finding the balance. *Report by the Northwest Educational Regional Laboratory* .

Scott S.D., M. R. (2003). Understanding children's collaborative interactions in shared environments. *Journal of Computer Aided Learning* , 220-228.

Scott, S. G. (2003). System Guidelines for Co-located, Collaborative Work on a Tabletop Display. *E-CSCW'03.* Kluwer.

Sedighian, K. (n.d.). *Super Tangrams*. Retrieved from http://www.cs.ubc.ca/nest/egems/supertangrams.html

Seymour Papert, S. T. (n.d.). Epistemological Pluralism and the Revaluation of the Concrete.

Shade, D. (. (1996). *Are you ready to teach young children in the 21st century? Early Childhood.* Educational journal.

Shade, D. (1996). Are you ready to teach young children in the 21st century? Early Childhood. *EducationJournal 24 (1)* , 43-44.

Sluis, R. J.-M. (2004). Read-It: Five- to-seven-year-old children learn to read in a tabletop environment. *Conference on interaction Design and Children: Building A Community* (pp. 73-80). ACM press.

Strommen, E. F. (1996). Slow and steady wins the race? Three-year old children and pointing device use. *Behaviour and Information Technology* , 57- 64.

Ullmer B. and Ishii, H. (2001). Emerging Frameworks for Tangible User Interfaces. *Human-Computer Interaction in the New Millennium* .

Ullmer, B. (2002). Tangible Interfaces for Manipulating Aggregates.

Weiser, M. (1991). The Computer for the 21st Century. *Scientific American* , 94-104.

Y fernaeus, J. T. (2006). finding design qualities in a tangible programming space. *SIGCHI.* ACM press.

Zuckerman, O. A. (2005). Extending Tangible Interfaces for Education: Digital Montessori- inspired Manipulatives. . *SIGCHI Conference on Human Factors in Computing Systems* (pp. 859-868). ACM press.